Alexander Popov Inventor of Radio

By M. Radovsky

Alexander Stepanovich Popov (1859-1905) was a Russian physicist, inventor of communication equipment and lecturer.

The best years of Popov's short life were spent in a school that was destined to become the cradle of radio. Here he worked for eighteen years, from 1883 to 1901. He came a youth without a stable place in life, and left the Torpedo School a recognized scientist that had glorified Russian science with an epoch-making contribution.

This period of Popov's life is of extraordinary interest not only as it concerns the biography of the inventor of radio, but also it regards the history of the theory of electricity and its practical applications.

The Popov Gold Medal is awarded annually by the Academy of Sciences of the USSR to Soviet and foreign scientists for outstanding scientific work and inventions in the field of radio.

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MEN OF RUSSIAN SCIENCE

M. RADOVSKY

Alexander POPOV

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by
M. Radovsky

Translated from the Russian by G. Yankovsky

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A. S. Popov (1859-1906)

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CHAPTER ONE

FROM CHILDHOOD TO UNIVERSITY

The industrial Urals is the homeland of Alexander Stepanovich Popov. He was born on March 16 (March 4, old style), 1859, in the village of Turyinskiye Rudniki, some 12 kilometres from the Bogoslov Copper-Smelting Works in Verkhoturye Uyezd of the Perm Gubernia (now Sverdlovsk Region).

In Popov's childhood, the village of Turyinskiye Rudniki was a good-sized centre. It had over one thousand homesteads with a population upwards of ten thousand. It was a lively industrial settlement with five mines, a machine works, and an iron works.

The environment in which Popov grew up provided a wealth of material for his inquisitive mind. The future investigator showed an exceptional interest in all sorts of technical structures, and as Doctor Deryabin, a playmate of Popov's at the time, writes: "His favourite pastime, in which I took part as assistant, was the building of different types of machines that worked mostly with the aid of running water. On the streams we built mills with water-wheels, hoisting machines with buckets for hauling ground out of 'mines' that were often dug to a depth of up to six and seven feet. Bars were also built. They were long horizontal moving beams like those in the factories. And we did many other things. He liked such construction work, and we were happy beyond measure when we succeeded and our 'machine' worked well. He was very clever in all of this 'machine building.' "

The recollections of others who knew Popov well are similar. All who knew Popov from childhood remark on his thirst for knowledge, which at an early age went hand in hand with a talent for creating and building. Slovtsov, the husband of Popov's elder sister, writes that the future scientist learned to read and write rather late, but he learned quickly and easily. Within a little over a month he prepared himself for the School of Theology in the town of Dalmatovo. Slovtsov knew many trades to perfection and he taught Popov carpentry and cabinet-making, both of which came in very handy later in his laboratory at Kronstadt (where nearly all his teaching and scientific work was conducted), because there were no shops nearby and so Popov had to construct different apparatus himself. These skills obtained in childhood were put to good use during his student years when he was left to himself and in order to earn a living had to do all sorts of hook-up jobs, a thing still uncommon at that early period in the development of electrical engineering.

One of Popov's schoolmates, Smolin, wrote: "I happened to attend the same school as Alexander. He was a very inquisitive boy. I recall the enthusiasm with which young Popov told us about the galvanic battery of cells, the electric bell, and the sewing-machine that he had seen in the manager's home at the copper mines. He was intensely interested in these new devices. He often went to the shops at the mines and spent hours watching the machines work. His love for machinery appeared when he was still a boy."

Popov very early became interested in natural science, and especially in the possibility of applying his knowledge practically. Professor Kapustin relates that Popov became interested in electricity at an early age.

Popov's father, a priest burdened with a large family,* tried to give his children a higher education, especially his sons. They all finished the University in the capital, and the younger daughters followed in their steps by studying in St. Petersburg too.

Before entering the University, where he made a thorough study of his favourite branch of knowledge, Popov completed the course of study common among the clergy, first the theological school, and then the seminary. The Dalmatovo Theological School, where he received an elementary education, was one of the oldest educational institutions in Russia, and was a century and a half old when Popov entered it.

At the Dalmatovo School, which had a four-year course, Popov spent only two years, and then went to live in Yekaterinburg where one of his elder sisters, Maria Levitskaya, lived. Yekaterinburg had its own school of theology, and here Popov completed his elementary education in two years. During this period he was looked after by his sister.

At that time, the next step for a priest's son was the seminary. In the Urals there was one located in the town of Perm, and in 1873 Popov entered it.

The social and political awakening in Russia that took place in the sixties and seventies of the 19th century was accompanied by a great spread of education in the country; the new ideas also made their way into the theological seminaries. Their seemingly impenetrable walls were not able to isolate the youth from the fresh atmosphere that was brought in by the thoughts and dreams of the revolutionary democrats of the sixties. The seminaries were not able to isolate the students and even a part of the teachers from the revolutionary movement that had begun in Russia.

The seminary in Perm was one of the first to feel the

* Popov had a brother, Raphael, and five sisters: Katherine, Maria, Anna, Augusta, and Capitolina. Alexander was the fourth child.

influence of the new ideas. At the beginning of the sixties, the local authorities discovered an almost revolutionary organization headed by three seminary teachers.

The vigilant eye of the seminary heads very soon got at the source of these "anti-religious and anti-government" ideas. "It has frequently been noted," wrote the rector of the seminary Lagovsky, "that the pupils of the seminary get secular magazines and newspapers which are prohibited on the grounds that they are of small value or even harmful for young people, and that such magazines and newspapers are given by a teacher of the seminary, A. V., notwithstanding the fact that he has been repeatedly warned not to give the pupils such magazines and newspapers."

The "sedition" was of course soon wiped out, and the bearers of such dangerous ideas were severely punished, but the influence of these courageous people on the following generations of students continued for a long time. The prominent Russian writer Mamin-Sibiryak, who studied at the same seminary as Popov (but earlier, from 1868 to 1872), characterized this influence as follows: "That period came to an end, although the memory of it is still fresh, and another period began, a period when our fathers had already finished the seminary and we had not yet begun studying anywhere; this was the glorious period of the seminary, which was followed by an instantaneous fall. It was a time when the intellectual movement gripped the whole seminary, when the professors of the seminary extended the hand of friendship to the pupils, when the seminary discharged at one stroke a galaxy of brilliant minds, the pride and glory of the school. But then a storm broke out—the professors were exiled and the brilliant minds were dispersed throughout the 'not too distant' provinces of Russia. This movement left a broad mark in the history of the seminary, it left stories and recollections that caused the hearts of honest and intelligent people to ache when they thought of the intelligent and honest people that had been hit by a wheel which crushed them."

It was during this period that a new type of youth was forming in the seminary; these new people strove towards real knowledge and took eagerly to the latest literary and scientific trends. The ideal of these young people was a university and not a theological seminary. The physiologist Pavlov, who also received his secondary education in a theological seminary, wrote in his autobiography: "Under the influence of the literature of the sixties, and especially of Pisarev, our intellectual interest turned to natural science, and many of us (myself included) decided to study the natural sciences at the University."

Perm had its disseminators of natural-scientific knowledge. From reports that appeared in the press during that period, it is clear that both here and in the capital as well as in the university cities lectures were organized for varied audiences that were interested in the latest attainments of science. The local gymnasium was a centre of the dissemination of such knowledge.

The seminaries too had teachers that upheld advanced pedagogical ideas and attempted to give their pupils a really complete secondary education in order to prepare them for conscious and useful activities in life.

These new ideas also influenced the seminary curricula which differed but slightly from those of the other secondary educational institutions.

In the seminary, Popov studied well in all subjects but especially took to the exact sciences, which he studied with such fervour that he was called "mathematician" by his schoolmates. Mathematics at that time, both in secondary school and in the university, embraced all the exact sciences.

Popov became interested in physics already in secondary school. His schoolmate, Korinfsky, with whom he kept up a friendship that lasted for several decades, beginning from his student days, relates that "while still a pupil of the seminary, he (Popov) was presented with a textbook of physics written by Hano, which had just been translated into Russian. It was this book that first stimulated his interest in physics. After reading it, there was no longer any doubt left in his mind that physics was his field." At that time it was a very popular textbook for beginners in physics, and was in circulation for several decades, running through a number of editions put out by the well-known publisher and educator of the last century, Pavlenkov. The popularity of the book during the seventies and eighties is to be explained, to a great extent, by the fact that Pavlenkov did not confine himself to a bare translation, but did much to make the text easy for the beginner, and he aroused in the reader an interest in this field of knowledge. In the introduction he wrote: "Knowing how dead is the knowledge of a pupil who restricts himself only to the theoretical aspect of physics, where there is almost no place for independent work, I found it necessary to supplement my translation with a considerable number of practical problems (over 200), the solution of which requires an intelligent application of physical laws." The lively, expressive language of the translation and the large number of fascinating historical facts developed in Popov an interest in the only subject of natural science that was offered at the seminary.

The question that confronted Popov when he completed the seminary was where to continue his education. The most attractive place was of course St. Petersburg, the centre of the cultural and political life of the country. For decades the intellectual youth of the democratic strata of society had come here; and by themselves, without any help, they made their way upwards towards a higher education preparing themselves to be useful members of society. This was the way of Raphael, Popov's elder brother, who had already gained a certain position in the literary field in St. Petersburg by the time Alexander had finished the seminary. These young people with their thirst for knowledge feared neither great distances (railways had just begun to cross the country) nor the unknown. The students made ends meet by giving private lessons, by working for newspapers and weeklies, and at other hackwork that took up a great deal of time and energy. This youth gave birth to many investigators, who later occupied a prominent place among scientists of world fame, and Popov was among them.

Full of hopes and aspirations, Popov arrived in St. Petersburg at the age of eighteen and submitted an application to the rector of the University for enrolment in the mathematics department of the faculty of physics and mathematics.*

On August 31, 1877, Popov became a student of the St. Petersburg University.

By this time the St. Petersburg University had already been in existence for over half a century. This wasn't very much for a higher educational institution (the Moscow, Derpt, Kazan, and Kharkov universities were older than the St. Petersburg University), but it was just at this time that the university of the capital began to flourish. Whole scientific trends and schools of thought were originating in certain faculties, while in others they were already fully developed. The faculty of physics and mathematics had many famous professors. Pavlov, who graduated from the natural science department two years before Popov enrolled, wrote in his autobiography: "This was a brilliant time for the faculty. We had a number of professors that commanded a tremendous scientific authority and that were exceedingly talented lecturers." In the exact sciences there were such men

* At that time, the faculty of physics and mathematics consisted of two departments: mathematics and natural science. The department of mathematics combined the chairs of physics, mathematics, meteorology, mechanics, and astronomy.

as Chebyshev, Butlerov, and Mendeleyev, whose lectures were attended not only by the students of the physics and mathematics faculty but by the whole University. The other faculties also flourished.

During those years, the chair of physics at the St. Petersburg University was headed by Professor Petrushevsky.* He did not limit himself to teaching physics only by lectures, he interested the students in practical, independent work in the laboratory. In Russia, Petrushevsky was the first to introduce laboratory work. His pupil, Lermantov,** wrote the following about his teacher: "Petrushevsky's great contribution was that he 'breathed a fresh life' into the teaching of physics in our University. Before, professors only 'delivered lectures,' as in any other subject that the student needed for his examinations; Petrushevsky was the first to see that the time had come when skill based on a knowledge of the facts of this science would be necessary in everyday life. He

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* Fyodor Petrushevsky (1828-1904) was honoured professor of the St. Petersburg University, the founder of the Physics Department of the Russian Physical and Chemical Society and for many years its President. A pupil of Lenz, Petrushevsky was head of the chair of physics and the teacher of several generations of physicists, among whom were some of the greatest Russian scientists in electricity and optics.

** Vladimir Lermantov (1845-1919) was lecturer at the St. Petersburg University and head of the physics laboratory. All those who graduated from the faculty of physics and mathematics and especially those who later devoted themselves to applied fields of knowledge, considered themselves indebted to the school they went through in the physics laboratory under the guidance of Lermantov, who had exceptional experimental capabilities and a rare talent for teaching this art to his pupils. In this respect, the majority of the outstanding Russian electrical engineers and opticians at the end of last century and the beginning of this century are first of all pupils of Lermantov; and among these the first place is occupied by Popov. Popov's bent for physical experiments that appeared early in childhood, flourished in the excellent conditions of the physics laboratory of the St. Petersburg University.

also saw that simply listening to lectures could not produce any skills, with the possible exception of the ability to take examinations. Real skills are obtained only by dealing with the real objects of the given science, i.e., in the case of physics with the phenomena of nature and with the instruments that serve to reproduce and to measure."

The atmosphere at the chair of physics of the physico-mathematical faculty stimulated interest in independent scientific research, and in working out new problems dictated by everyday life. As a result, within some ten to fifteen years, the St. Petersburg University produced a large number of physicists that later headed the chairs of physics in different higher educational institutions. In the eighties and nineties of last century, such professors as Shatelen and Mitkevich of the Leningrad Polytechnical Institute, Sadovsky of Derpt University, Kapustin of Tomsk University, Lyuboslavsky of the Forest Institute, Lebedinsky of the Riga Polytechnical Institute, Georgiyevsky of the Technological Institute, Gershun of the St. Petersburg Higher Women's Pedagogical Courses, and Petrovsky of the Mining Institute, received the same schooling as Popov. The above is only a very brief list of Popov's closest friends, comrades and associates, and could easily be continued.

A remarkable feature of the St. Petersburg school of physics was that the graduates of the University sought every opportunity to apply practically the achievements of their science.

The history of electrical engineering in Russia has not yet been written, but the investigator who begins this remarkable page in the history of material culture will, when speaking of scientific electrical engineering, first of all name the faculty of physics and mathematics of the St. Petersburg University, since it was this faculty that produced the first Russian scientists who created whole trends and schools of thought in electrical engineering. There is no exaggeration in saying that many sections of technical physics are rooted in the St. Petersburg University of the last quarter of the 19th century. This also applies to electrical engineering and optics. The creators of optics, Gershun, and especially Rozhdestvensky, were both of the St. Petersburg University, which graduated such men as Shatelen, Mitkevich, Lebedinsky, and Petrovsky, who laid the foundation of scientific electrical engineering in Russia and who trained the electrical engineers that headed Russia's electrical industry and its branch, radio engineering. These scientists began working on a broad scale as soon as Russia established her own special schools of electrical engineering.

Higher schools of this type appeared in Russia at the end of the 19th and the beginning of the 20th century, although the need for qualified specialists in electricity was felt much earlier. Whole branches of electrical engineering, for example, wire communications, electrochemistry (galvanoplastics), and electric lighting, were becoming a part of everyday life and required more and more scientifically trained men. At first it was mainly the graduates of the physics and mathematics faculties of the universities that trained such specialists. In this respect, the St. Petersburg University occupied the leading place. Not only the students but also the professors and teachers were closely connected with electrical engineering. Petrushevsky and his pupils, Borgman*

* Ivan Borgman (1849-1914) was honoured professor of the St. Petersburg University; he also taught in other higher educational institutions, including the Electrotechnical Institute, where he was elected honorary member of the council. His teaching career at the University began during the student years of Popov. Like all the Russian physicists of the last quarter of the 19th century who studied at the St. Petersburg University, Popov's physical views were obtained mostly from Borgman. It was he, as Lebedinsky points out, who was such a staunch supporter of the theory of Faraday and Maxwell, from which theory the inventor of radio "received the first prerequisite to the utilization of electromagnetic waves." In the course of many years Borgman contributed to this

and Khvolson* were actually the first teachers of a course devoted to the scientific principles of electrical engineering which was then called "Electricity and Magnetism." This course, which formed the physical basis of electrical engineering, was delivered by Petrushevsky, and then later by Borgman and Khvolson in special schools until special courses were introduced. To this day the curricula of higher electrotechnical schools are based on these courses.

Thus, we see that the situation which Popov encountered on his arrival in St. Petersburg was extremely favourable for the development of his scientific interests,

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great cause of his pupil. When, after Popov's death, a prize named after him was established and one of the sources for raising funds was to be the income from public lectures, Borgman was the first to participate.

* Orest Khvolson (1852 1934) was honoured professor of the St. Petersburg (later, Leningrad) University, where he taught for nearly 60 years. He was also Honorary Member of the Academy of Sciences of the U.S.S.R. Not only the students of the higher educational institutions in which Khvolson taught (he taught at the Electrotechnical Institute, the Higher Women's Courses, and the Institute of Railway Transport, besides the University), but also all the Russian physicists that had studied his multi-volume course, which was translated into many languages, considered themselves his pupils. Academician Vavilov, a graduate of the Moscow University, wrote: "One may state with certainty that there is not a single physicist in our country who has not gone through the Khvolson school."

Khvolson gained this reputation even before he created his course. The beginning of it was a series of public lectures entitled "Electricity and Magnetism," delivered in St. Petersburg during Popov's student years at the request of the Sixth Department (Electrotechnical) of the Russian Technical Society. Crowds of students from different schools in the capital and also those already working in the field of electricity came to Khvolson's lectures.

There can be no doubt that Popov, whose deep interest in electricity appeared while still a student, attended these lectures and was one of the first research physicists to go through the Khvolson school.

and it gave a definite direction to creative thought. He made excellent use of these broad possibilities, since even as a student he showed a definite bent for this field of scientific and applied knowledge in which he was later to become famous.

However, the young student had to think of earning a living; if he were exempt from paying for his right to study, it would have helped greatly. Popov presented to the University Council a certificate issued by the Perm Theological Consistory "concerning the insufficient funds" of his father, and was exempt, although not at once, from paying for lectures. Later he applied for a scholarship, which was granted. In addition, Popov had to give private lessons because two of his sisters, who had come to St. Petersburg with him, were also in need of money. Later, in his last years at the University and after graduating, he worked in the Elektrotekhnik Company.

Although we know very little about the first steps in Popov's career, they are of great biographical interest. Our information is limited to the facts given in a book written by Shatelen* who knew the Elektrotekhnik Company from personal experience. Here is what Shatelen re-

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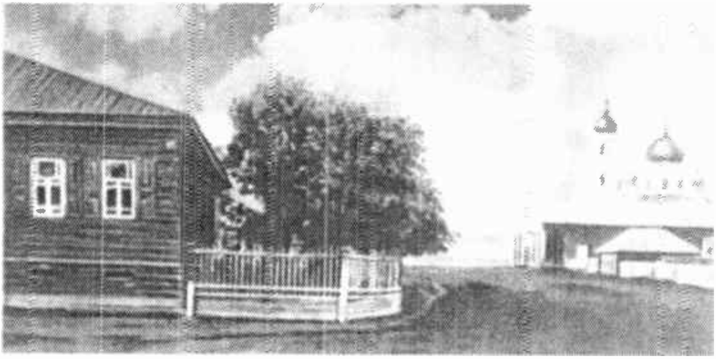
* Mikhail Shatelen (born 1866), honoured scientist, Corresponding Member of the Academy of Sciences of the U.S.S.R., the first professor of electrical engineering, and the author of the first textbooks on this subject in Russia. He was elected to a chair of the Electrotechnical Institute in 1893. Shatelen is known for his scientific investigations in the field of high voltages, electrical measurements, and the history of electrical engineering, and also as a teacher, statesman and public figure. He was one of the chief participants in the drawing up of the GOELRO plan (the State Commission on the Electrification of Russia) approved in 1920.

Shatelen was seven years younger than Popov, who had already graduated from the St. Petersburg University a year before Shatelen entered it; nevertheless their personal contacts began during Shatelen's student years. Their work together in the physics laboratory, which they continued even after the University while working at other places, was what united them.



The house where A. S. Popov was born in the village of Turyinskiye Rudniki

The home of the Popovs. A part of an "electric alarm clock" that Popov made when a boy is seen in the upper right corner (A drawing made by Popov's sister, A. S. Popova-Kapustina)

A. S. Popov at the University (1878)

lates: "At this early period in his career, Popov became interested in electricity and took a job in the Elektrotekhnik Company which had just formed in St. Petersburg. This company handled arc-type electrical lighting in gardens and public institutions using Chikolev's differential lamps almost exclusively; it also built small-size power stations for private use. Later, it built a public power station in St. Petersburg on a barge on the Moika, not far from the bridge across the Neva Avenue. In 1880, the Company advertised that it would handle electric lighting for railway stations, railways, print shops, factories, workshops, hotels, restaurants, warehouses, clubs, theatres, gardens, squares, bridges, and streets, and the like. The Company's advertisements carried a picture of a Chikolev lamp. The advertisement said that 'electric lighting with differential lamps is the cheapest type of lighting.' "

Shatelen writes that Popov "had to deal with hook-up jobs and also the maintenance of small-size electric stations which the Company built. These maintenance conditions were often rather original. For example, in the lighting of one of the amusement parks in St. Petersburg, where it was Popov's job to regulate the voltage of the dynamo by varying the number of revolutions, the role of the voltmeter was played by a boy (since there weren't any electrical measuring instruments) who stood near the lanterns and yelled out to Popov: 'Some more,' when the lanterns, in his opinion, began to burn too low."

This constant worry about earning a living did not, however, hinder Popov from getting good marks at the University, nor did it interfere with his active participation in the life of the scientific circles of the capital. At that time it was not only the higher educational and research institutions in St. Petersburg that carried on scientific work; scientific societies were likewise engaged. Among them a special place is occupied by the Russian Society of Physics and Chemistry, and the Russian Technical Society. The first was connected with the St. Petersburg University, and the second was an independent scientific corporation. It was at this time that the Sixth Department (Electrotechnical)* of the Russian Technical Society was established with its journal *Electricity*.

In the history of electrical engineering in Russia, the part played by the Sixth Department of the Russian Technical Society is outstanding. In pre-revolutionary Russia there were only a few special scientific research institutions, especially of the applied type, and therefore Russian scientific societies had to use their own money for the elaboration of topical scientific problems; they had to co-ordinate the efforts of individual investigators and at the same time conduct a broad programme of dissemination of scientific knowledge. In this respect, the activities of the Sixth Department are especially characteristic.

During the very first year of its existence the Sixth Department organized an electrical exhibition in St. Petersburg.

Both the exhibition and the journal played a very important part in the history of electrical engineering in Russia. Their aim was the same, that of attracting the attention of broad circles of Russian society to this new technical field, that of creating the most favourable conditions for its development; at the same time, the aim was to show that Russia was sufficiently prepared for the solution of outstanding problems in electricity.

The first issue of the journal *Electricity* carried a report on the exhibition. This was the first electrical exhibition in the world. As Shatelen wrote, "one had to have courage to risk organizing such a special exhibition in such a backward industrial country as Russia was at that time,

* Up till then the Society had had the following departments: I—Chemical Production Processes and Metallurgy, II—Mechanical Technology, III—Mechanics and Machine-Building, IV—Construction and Architecture, V—Photography.

when exhibitions of that type were not being organized even in the more industrialized countries: the first electrical exhibition outside Russia was opened in Paris only in 1881, i.e., a year later."

The exhibition organized by the Sixth Department was a great success. The leading article of the first issue of the *Electricity* said that "the interest in this new force here in Russia has grown considerably of late, and an indication of this is the large number of visitors who every day, from morning till night, filled the halls of the first Russian electrical exhibition that took place this year, notwithstanding the fact that this exhibition did not present (nor was it in a position to, for the matter was so new) a full picture of the envious position that electricity already justly occupies in our century."

The exhibition consisted of eight sections: telegraphy and telephony, electric lighting and electro-mechanics, electricity in the army and navy, galvanoplastics, electricity in education, electrical measuring instruments, electrotherapy, and, finally, literature and pictorial material on electricity. The works of such Russian inventors as Yablochkov, Lodygin, Chikolev, Bulygin, Lachinov, Kovako, Rikhter, Ragozin, Kresten, Alexeyev, and Teplov were represented in all these sections. Whole institutions and departments were represented, for example, the Department for the Manufacture of Securities,* the Artillery Management, the Naval Department, the General Staff, the Telegraph Department, the Forest Institute, and the Pedagogical Museum.

Visitors to the exhibition did not only look at the exhibits, they also had the opportunity of becoming more closely acquainted with them. Explanations were given by prominent specialists, inventors, engineers, and scien-

* Electricity for the first time found a broad field of application in the Securities Department. Yakobi's invention of galvanoplastics began to be used in the manufacture of bank-notes and other valuable papers

tists, among whom we find the name of the famous Russian chemist Butlerov. They gave "special explanations with experiments." This contributed a great deal to making a success of the exhibition, which actually was turned into a real centre for the dissemination of scientific and technical knowledge. The exhibition lasted nearly a month, and was visited by over six thousand persons. It not only paid for itself, but also brought in a considerable profit (over one thousand two hundred rubles) which formed the main source for financing the first electrical journal. At the same time, the exhibition was a sort of practice seminar for the students of the University studying at the faculty of physics and mathematics and interested in electricity and its practical application. The young people participated in the preparatory work and helped at the exhibition itself. The theoretical facts gotten from lectures and the knowledge obtained in the laboratories were made good use of here. The students profited greatly from their acquaintance with the machines, apparatus and instruments, which were the best that the schools had and that industry at that time could produce.

Popov, then a student, took an active part in the exhibition, working as a guide. His classmate, Korinfsky, said that Popov was especially interested in problems of utilizing high-voltage direct and alternating current.

By that time, Popov already had a sufficient knowledge of electricity, acquired, incidentally, by himself. Lebedinsky* who later also studied at the St. Petersburg

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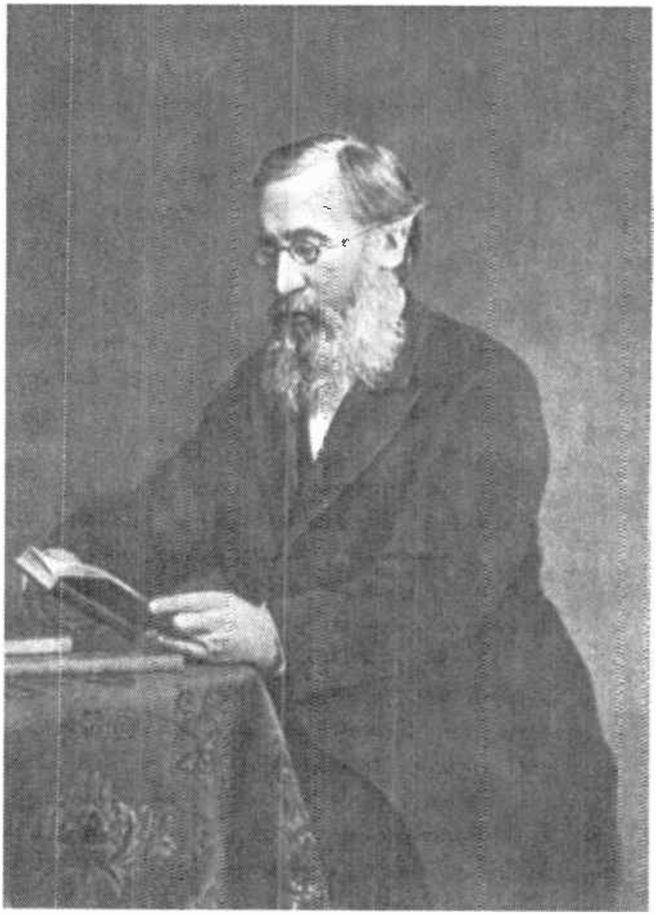
* Vladimir Lebedinsky (1870-1937) was professor in a number of higher educational institutions. He was one of the pioneers of theoretical electrical engineering in Russia, and together with Petrovsky, was the author of the first manuals on wireless telegraphy (its physical principles). He was a prominent popularizer of science and did much to disseminate knowledge connected with the new field of communications. He was the editor of classical works in this field that were the handbooks of several generations of Russian radiomen. If we exclude Popov, then Lebedinsky and Pet-



F. F. Petrushevsky (1829-1891)

A. S. Popov (third from left) and his fellow students

A. S. Popov with his wife (1882)

University and was personally acquainted with Popov, relates: "The University teachers taught us to think; they opened up the book of science, and the pupils wanted to understand their teachers better. At the same time, life began to demand the practical application of electricity, and one felt a desire to participate in this movement. Self-perfection, or better still, the beginning of a real understanding, the happiness of grasping the subject appeared in the work of scientific circles."

The memoirs of other contemporaries of Popov, of those who knew him well and saw him often, produce the same picture of the creative inquiries of a small group of Russian electricians linked by their constant contact in a field of common interest. Actually, all the activities of the Sixth Department and the editorial board of the *Electricity* were in the form of work in "scientific circles." In his memoirs, Mitkevich* had the following to say: "Russian

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rovsky share the honour of being the first teachers of radio engineering in Russia; they were the ones who introduced this subject into the higher technical schools.

Throughout his whole life Lebedinsky never tired of popularizing Popov's invention. He was the initiator of the movement, which developed on a large scale after the Great October Revolution, for the rehabilitation of Popov's rights as the inventor of the new type of communication. Lebedinsky's recollections about the inventor of radio contain not only important facts from his biography but also serve as valuable material for the writer of a history of Russian science (physics and technology) at the end of the 19th century and the beginning of the 20th century.

* Vladimir Mitkevich (1872-1951) was an honoured scientist, a member of the Academy of Sciences of the U.S.S.R., and an outstanding representative of scientific electrical engineering. His works touched on a number of fields in electricity, including problems of high frequencies. Contacts with Popov began in his student years. In 1893, Mitkevich, then a fourth-year student, went to the Chicago World Exhibition, where Popov had been sent as a delegate from the Naval Department. Mitkevich's letters about the exhibition were printed in the newspaper of his home town *The Minsk Leaflet* (August, 1893).

electrical engineers and scientists often gathered in the editorial office of the *Electricity* which was located in Smirnov's flat. We spoke about the affairs of the journal, we argued and discussed matters, and then the good-natured and hospitable host would call us to dinner, at which there began, in this absolutely informal atmosphere, friendly talks dealing very often with the journal and with problems of modern electricity. It was here that for the first time I had the opportunity of meeting and becoming more closely acquainted with a large number of outstanding personages who had done theoretical and practical work in the field of electricity. Among them were such men as Popov, Chikolev, Lachinov, Yegorov, Borgman, Shatelen, Lebedinsky, Gershun, Voronov, Georgiyevsky, Skrzhinsky, Imshenetsky."

It is characteristic that in this list we find both Popov's teachers and his junior contemporaries. Despite the difference in age and position, this was a closely-knit family of Russian electricians and scientists. Popov entered it while still a student, and he remained intimately connected with it to the end of his days.

The Sixth Department of the Russian Technical Society opened wide its doors to all interested in the new technical field, but it especially attracted the youth. And Popov belonged to this group of young people. By the time he had completed his course at the University he was not only a physicist with a university degree, but also a mature and well-educated electrical engineer. Popov's broad activities as an engineer developed much later, but he

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Closer relations between Mitkevich and Popov were established during Mitkevich's work in the editorial office of the *Electricity* as scientific secretary.

Popov's name is connected with Mitkevich's first big scientific achievement. He received the Popov Prize for his classical work entitled *On the Mechanism of the Voltaic Arc*. This was the first Popov Prize, awarded on December 31, 1906, on the anniversary of his death.

received his technical training while still a student. He evinced rare capabilities for independent research work, which was noted by his teachers at the University.

Popov completed the course at the University brilliantly: he was graduated with the degree of Candidate, which was conferred on him by the Council of the University on November 29, 1882.

The University course, if successfully completed, was consummated by the presentation of a dissertation (for the students who were graduated with the degree of Candidate of the given university, as distinguished from those who completed their course with the title of Graduate). Of Popov's dissertation entitled "On the Principles of Direct Current Magneto and Dynamo Electric Machines," Professor Van der Flit* wrote as follows: "I consider Mr. Popov's dissertation in every way satisfactory; it is a very detailed and conscientiously executed piece of work." Due to this opinion as well as to the excellent marks he received at the examinations, Popov was considered worthy of the scientific degree of Candidate. After completing his course, Popov was offered a position at the University, which he accepted.

It would seem that a brilliant career was opening up to the young scientist. But the road to a professorship was neither direct nor easy. The number of staff teachers was very small. The funds that were allotted for scientific purposes in pre-revolutionary Russia were insignif-

* Petr Van der Flit (1839-1904) was honoured professor of the St. Petersburg University and one of Popov's teachers. He worked on many problems of physics and paid special attention to electricity. His most fundamental work is a monograph entitled *A Physical Theory of Electric Current* (1881). Contemporaries, characterizing the school that the inventor of radio went through, give, among others, the name of Van der Flit when they point to the professors that influenced a generation of Russian physicists that graduated from the St. Petersburg University at the end of the last century

icant. The chair of physics, and also the other chairs, never had more than two professors on the staff, whereas the lecturers were remunerated only when they had obligatory courses, which happened at faculties with a large number of students, for example that of law.

Popov was already a family man when he graduated from the University. Earlier he had given lessons to a certain Raisa, the daughter of a St. Petersburg lawyer, Alexei Ivanovich Bogdanov. The young pair became friends, and their friendship soon developed into a deep affection. Popov's pupil, later his fiancée, had received a secondary education, after which she entered the Medical Courses for Women. Her father died at this time, and Popov had to think about making enough money to support the family. It just happened that at the time (1883) there was an opening for a teacher in the Torpedo School in Kronstadt.* It was offered to Popov and he accepted.

Twenty-four-year-old Popov began teaching in an institution which at that time had shown itself to be an excellent school for army electricians; also it had the best laboratory in Russia, a laboratory in which the most complicated experiments could be conducted.

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* Kronstadt is a town on the island of Kotlin in the eastern part of the Gulf of Finland. It was founded in 1703 by Peter I as a fort and base for the defence of St. Petersburg from the sea.

CHAPTER TWO

THE TORPEDO SCHOOL

The best years of Popov's short life were spent in a school which was destined to become the cradle of radio. Here he worked for eighteen years, from 1883 to 1901. He came a youth without a stable place in life, and left the Torpedo School a recognized scientist that had glorified Russian science with an epoch-making contribution.

This period of Popov's life is of extraordinary interest not only as concerns the biography of the inventor of radio, but also as regards the history of the theory of electricity and its practical application.

Since 1855 when James Clerk Maxwell published his first work *On Faraday's Lines of Force,* the science of electricity had experienced a period of intense development, a period which was characterized both by profound theoretical thinking (Maxwell's two-volume *Treatise of Electricity and Magnetism,* 1873, in which he formulated the electromagnetic theory of light) and by a wealth of new experimental data. Especially brilliant results were obtained by H. Hertz, who proved experimentally the existence of electromagnetic waves and who had followers in many countries, including Russia.

Popov differed from the majority of his predecessors who had worked on problems of electric waves and oscillations in that as a scientist he grew up in an environment which, to a great extent, favoured attempts to apply practically the achievements of science. Even as a student he was close to scientific and technical circles, the aim of which was the development of this new field of technology by utilizing every advancement in the science of electricity. After the University he again found himself in similar conditions.

It wasn't by chance that the Torpedo School became the cradle of wireless telegraphy. Documents and material dealing with the history of this educational institution show that the ground here was favourable for bold scientific and technical ventures.

The Torpedo School was founded in 1874 and was to train both torpedo-men and electricians. The school was located at Kronstadt to ensure constant and close contact with the Navy. This had its difficulties, especially at first, when it didn't have (nor could it have) teachers on the staff working for the Naval Department only. Nevertheless, the best specialists of the capital were invited to teach. They not only taught the cadets but also trained assistants (provided for in the personnel plan) to take their place.

At the head of the school was an officer appointed by the Naval Department from among the commanders of the Torpedo Detachment. At first the school had an annual enrolment of twenty students from among the officers of the Navy, who were exempt from examinations. They were so-called "obligatory cadets." Besides them, extern students from among the naval officers were allowed to enter. The very first year there were several times more such students (as many as 70 persons) than there were "obligatory cadets."

The course of class instruction lasted only six and a half months, from October 1 to April 15 (later it was considerably extended when the so-called supplementary course was introduced). After examinations and a sea voyage, those who had successfully completed the course received commissions as torpedo officers on the ships of the Navy.

At first, the school had only three subjects, with the course of electricity (it was called "An Experimental and Practical Course in Electricity, Galvanism, and Magnetism") occupying first place. This was followed by a course in explosives, and a special course on submarine mines.

The school also had a torpedo division with 40 cadets "selected from among well-trained gunners recently graduated and who know arithmetics." This was a detachment that trained privates, torpedo-men and non-commissioned officers of this arm of the service.

During the very first years of its existence, the Torpedo School had shown itself capable of training specialists that could tackle extremely complex technical problems. Thus, for example, in 1883, during the coronation of Alexander III, the electrical illumination of the Kremlin, which was a grand undertaking for that period, was handled by the graduates of the school.

The contribution of the Torpedo School was not only in the training of electricians. Of exceptional significance is the fact that the teachers were given favourable conditions for scientific research work. Even a university could envy such conditions. The physics laboratory and the rich scientific library that was constantly being supplied with the latest Russian and foreign literature, could satisfy the very highest demands. Popov's closest associate, Georgiyevsky,* who later headed this laboratory, wrote:

* Nikolai Georgiyevsky (1864-1940) was professor at the Leningrad Technological Institute. A pupil of Yegorov, Georgiyevsky was his assistant in the Military Medical Academy. Together with his teacher he conducted valuable research in the verification of the Zeeman effect.

Although the most important works of Georgiyevsky have to do with heat, he was among the prominent members of the Sixth Department (Electrotechnical) of the Russian Technical Society and the chief organizer of congresses in electricity.

Georgiyevsky was connected with Popov from the very beginning of his independent scientific career, while working as assist-

"This concern for raising the teaching level in the school resulted in the establishment of what was probably the best (both in variety and selection of instruments) physics laboratory in Russia at that time. It was well financed and it improved from year to year. The school had its own library that received the most important foreign magazines in physics and electricity." Rybkin (1864-1948), who was head of the physics laboratory after Georgiyevsky, said the same about this birthplace of wireless telegraphy.

Even before Popov, the Torpedo School had conducted intensive research work. Within 10 years of the founding of the school, the authorities began to make demands on it as if it were a research institution. This is made special note of in *The Materials on the History of the Torpedo School*, where each chapter contains a special section devoted to scientific investigations conducted in the school. Reports of these activities began in the eighth year of the existence of the institution.

It should be added that the Torpedo School had its own organ, *The Torpedo School News*. Although the *News* was not a strictly periodic publication it was coming out at least twice a year by the time Popov came there to teach (the last issue was its fifteenth in 1885, when it was renamed *Torpedo News* and was put out by the Naval Technical Committee). Popov also participated in this organ which published his articles, "On the Hughes Induction Scales" and "The Syllabus of Revision Instruction on Differential and Integral Calculus."

It has already been pointed out that the Torpedo School

ant in the Torpedo School during the years before the invention of radio (1890-1894). Their close and friendly relations continued to Popov's last days. Georgiyevsky's memoirs *The Works of Popov That Preceded the Invention of Wireless Telegraphy* (*Electricity*, 1925, No. 4, pp. 211-215) are one of the main sources for the study of Popov's work during the period just before the invention of radio.

N. G. Yegorov (1849-1919)

A. S. Popov among the participants of the Krasnoyarsk expedition was not only an educational institution but also a scientific establishment. And not only the teachers were engaged in scientific investigations. The youth also were drawn into this creative work, an additional course being established for the purpose. Thus, the teachers had to do with people who would later develop the field of knowledge to which they had dedicated themselves.

Popov entered the school in its tenth school year (1883-84) and at once began teaching at the basic and supplementary courses. A year had hardly passed when, because of the illness of one of the teachers (Stepanov), Popov was asked to deliver an independent course of lectures on electricity. Popov's first biographer, Smirnov, who was well acquainted with the inventor, wrote that "in 1884-85 the young assistant had to replace one of the teachers, Stepanov, who was taken ill; this responsible course quickly developed Popov, it extended his knowledge and helped him to master his shyness."

The lecture course on electricity did not, however, free Popov from his other duties. He continued the "revision course on differential and integral calculus," remained head of the physics laboratory, and conducted laboratory work in electricity and magnetism. And in 1885-86 he conducted a short course in electricity, and also laboratory work in electricity in the Class of Torpedo Mechanics.

Already during Popov's second year in the Torpedo School, his official position enabled him to take up the study of his favourite subject and stimulated his interest in independent creative work. Very few of Popov's personal notes still exist, especially such as might contain original pedagogical or research ideas. Popov differed from some scientists who collected their notes and letters with the utmost care producing in this way extremely rich scientific archives (the daily notes of Faraday, for example, form seven huge volumes, and Yakobi's notes and papers number tens of thousands and reflect various stages of his activities from the very beginning of his independent work), in that he did not leave after him any such material. Petrovsky,* the teacher who succeeded Popov in the Torpedo School and who knew him well, related the following in a speech dedicated to the memory of the inventor of the wireless telegraph: "Although Popov taught in several educational institutions he left behind very few personally written notes. His numerous public lectures and reports on wireless telegraphy were not published, and the whole history of the discovery that made Popov world famous, remained only in the recollections of persons who were witnesses of the event."

Popov himself wrote the syllabus of his lecture course. The compilers of *The Materials on the History of the Torpedo School* published this syllabus. It permits one to judge of the level of development of this field of physics and about the trend which the young teacher tried to introduce into his lectures. Following the part devoted to theoretical principles, there is a section on the practical application of the theory of electricity. From the present-day viewpoint, the syllabus may seem very modest, especially the last part that deals with problems of electrical engineering.**

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* Alexei Petrovsky (1878-1942) was an honoured scientist and the first professor of radio engineering in Russia. He began independent scientific and pedagogical work first in the Technological Institute, where he remained for only a short time, and then extended it in the Torpedo School after Popov who selected him as his successor had left.

Petrovsky considered himself Popov's pupil, and also continued the work of his teacher. He was head of the first scientific research radio laboratory established in the Naval Department and attached to the Radio Telegraph House. The name of Petrovsky is connected with the first steps in the elaboration of the problem of utilizing electromagnetic waves for geological prospecting and as a means of communication in mines.

** Petrovsky in the speech mentioned above wrote about this period as follows: "At that time, Russian electrical engineering

Therefore the few lines that make up Popov's entire lecture programme of the first course are certainly of interest: "Lectures on electricity. Electrostatics. The basic electrical phenomena. The C.G.S. system. The laws of electrical forces. Electric machines. The Leyden jar. Electricity of contact. Galvanic cells. Magnetism. Basic magnetic phenomena. Distribution of magnetism in magnets. The laws of magnetic forces and magnetic measurements. Electrokinetics. On the motion of electricity in general. The electric discharge. The action of current on a magnetic needle. The laws of electric current. Measurement of resistance. Measurement of electromotive forces. Thermoelectricity. Heat action of current. Chemical action of current. Mechanical and physiological action of current. Magnetic action of current. The interaction of currents and the action of magnets on currents. The basic phenomena and laws of the induction of currents. Induction instruments. Terrestrial and atmospheric electricity and terrestrial magnetism. Certain practical applications of electric current. Galvanoplastics. Electrical transmission of work. The telegraph, telephone and microphone. The distribution and measurement of the energy of an electric current." Such, in general outline, were the courses in electricity of that time. As a rule, they contained information concerning practical applications in this field of physics, from the generation of electricity to the consumption of electrical energy.

It is true, however, that Popov's course did not embrace the whole field of contemporary electrical engineering. Generators (at that time they were dynamos, i.e., direct current machines) and drives (electric motors) were not included. The officers that were trained here did not have to deal (in actual practice) with the generation of electricity but with its distribution and consump-

'was in swaddling clothes,' as Popov himself put it, and the Electrotechnical Institute, the real disseminator of specialized knowledge, was yet to have its founder."

tion. However, it soon became clear that one could not be a qualified electrician without a thorough knowledge of the source of electrical energy, as well as the electric motor, the chief consumer of electricity. And Popov himself was one of the first in Russia to write a course on dynamos and electric motors, which became obligatory for the cadets. We are indebted to some of the cadets for preserving for us Popov's course on electric motors, which serves as valuable material on the history of electrical training in Russia. Up until Voronov's well-known course appeared, Popov's lectures were one of the few manuals in the Russian language that could help the students in preparing the subject of electric motors, which was one of the most important subjects in the field of electricity.

Even as a student, Popov had nothing to do with the trend whose motto was "science for science's sake." Like all other leading scientists, he was convinced that scientific research, especially in the field of natural science, should be aimed at applying the achievements of the investigating mind. And throughout his whole life he acted on this principle. Popov taught in a school of applied science, and he gave a practical bent to the general lecture course in physics, which even officially was called "practical physics." In the *Materials* we find: "In September of 1888 instructor Kapustin* was invited to Tomsk University and therefore could not continue

* Popov's immediate predecessor in the general physics course was Kapustin, Mendeleyev's nephew (the son of the great chemist's eldest sister) who studied at the same faculty and department of the St. Petersburg University as Popov. They were first friends and then later relatives (Kapustin was married to Popov's sister, Augusta, who had come to St. Petersburg with Popov). Unlike Popov, Kapustin did not work on the application of scientific achieve ments, he was what was then called a "pure physicist." After his term at Tomsk expired he returned to St. Petersburg without having accomplished anything much in science. His little-noticed activities in the Torpedo School are given but brief mention in the *Materials*.

M. A. Shatelen, present Chairman of the All-Union Society of Electricians

A. S. Popov in Chicago. Next to him is the Russian electrician, M. O. Dolivo-Dobrovolsky instruction in the school; his subjects were divided up between instructors Stepanov and Popov, with Popov entrusted with the delivery of lectures and the conducting of laboratory work in practical physics, and Stepanov with laboratory work in electricity."

The young instructor was engaged not only in teaching, but also in scientific investigation. Contemporaries recollect that Popov spent all his time in the laboratory, busy from morning till night, both on week days and holidays, with his research and without the help of any assistants. Petrovsky recalls that "despite the considerable number of obligatory lessons, Popov spent nearly all his free time in the laboratory. He didn't know what it was to rest. Every Sunday and every holiday, to say nothing of the week days, he could be seen in the Torpedo School. He himself did the greater part of the small jobs that were necessary in his research; he wound coils, bored holes, did the glass-blowing, and soldered the parts of his instruments. One can judge what skill he attained in this work by the fact that the first relays used in the experiments with wireless telegraphy were made from old voltmeters."

Though busy at Kronstadt, Popov was in no way cut off from active scientific life in the capital. He valued very highly his connections with the scientific institutions and organizations of St. Petersburg, such as the University, the Physical and Chemical Society, and participation in the work of the Sixth Department of the Russian Technical Society with which he had been connected ever since his student years.

The Russian Physical and Chemical Society, the first scientific organization that acquainted the world of science with the practical possibility of transmitting signals without wires, occupies a prominent place in the history of Russian science. It was founded on the initiative of Mendeleyev in 1878 as a result of the merging of the Physics Society (founded in 1872) and the Chemical Society (founded in 1868).

The Society's *Journal of the Russian Physical and Chemical Society* published the works not only of its own members but also of other Russian physicists and chemists, and was for a long time the only periodical on physics and chemistry that reflected the scientific life of the country in this field. It is hard to name a single considerable event in the history of Russian physics and chemistry which was not reported to the Society or which did not appear on the pages of its journal. It is not possible here to dwell on the more outstanding achievements of the physical and chemical sciences in Russia during the second half of the 19th century. Suffice it to say that Mendeleyev's investigations which culminated in the periodic system of elements were the subject of his reports in the Physical and Chemical Society, and his memoirs on this subject were first published in the Society's journal.

The documents and materials pertaining to Popov's activities during the period preceding the invention of radio are scanty. But the pages of the *Journal of the Russian Physical and Chemical Society* have kept for us valuable information concerning his speeches delivered in the Society. These speeches reflect Popov's scientific interests and they also show the direction of his own investigations; such facts are all the more valuable since Popov was over-scrupulous in the question of publishing his works. This is the way Petrovsky described him: "There are two types of people. The first have a weakness for the printed word, and attempt to publish every idea, even before it has fully taken shape, the second work in the quiet of their laboratories and only insistent requests force them to take up their pens. Popov was an extreme type of the latter. He didn't like to write."

A very large number of Popov's investigations were never published, and mention of them can be found only in the science chronicle of the *Journal of the Russian Physical and Chemical Society,* which was careful to make note of all the speeches in the Society that merited attention. This source, which is so valuable for the history of Russian science, tells the story, though briefly, of the state of science at that time, of the interests that inspired the individual investigators who were quick to respond to the problems of the day. This journal is especially valuable as material for Popov's biography. His biographer, who is forced to collect piece by piece data concerning the diverse activities of the inventor of radio, finds here unique facts, even though they are disconnected and scanty.

Popov's first paper was read in the Society in 1885, two years before he was elected member of the Physics Department. It was only much later that Popov again reported to the Society. To a certain extent this is to be explained by his shyness. However, later on, he began to speak at large meetings, sessions, congresses, and conferences rather often. In this his environment helped him. A considerable part of the intellectuals from among the commanding officers of the fleet, the ships and the coastal service (which had at its disposal large numbers of engineers and technicians), and the teachers of the naval schools were concentrated at Kronstadt. They were all connected through the so-called Naval Society. At Kronstadt, prominent personages in the Navy and teachers of the naval schools often read papers that were devoted to different scientific topics. In selecting the topics, the lecturers kept in mind chiefly one aim, that of reporting the latest news of their field in which they were specialists. Popov, who by then was already occupying a prominent position in the Torpedo School, could not but participate in these meetings. He addressed the naval officers many times, and these speeches that began before the reports to the Physical and Chemical Society served as a sort of preparation for the latter.

In the Russian Physical and Chemical Society Popov's papers were devoted to the results of his own experiments and observations. The minutes of the Physical Department of the Society, beginning with 1892, report these papers year after year. All of them had to do with the latest achievements of science and were distinguished by an expert demonstration of experiments, which are now acknowledged as classical. Among these papers were: *An Experiment Illustrating the Gradual Increase in Current in a Circuit (Helmholtz's Law) with a Small Resistance and Considerable Inductance*, and *An Experiment with the Hopkinson Iron-Nickel Alloy*.

Prior to his famous address *On the Relation of Metal Powders to Electric Oscillations*, which was the starting point in the history of radio, Popov reported twice to the Physical and Chemical Society. In his first paper (December 1893) he demonstrated Young's magnetic model composed of a large number of small and highly mobile magnets placed between two parallel plates of mica. A year later, in November 1894, Popov read a paper entitled *A Case of the Conversion of Heat Energy into Mechanical Energy*. Unlike the previous papers that were reported in the minutes of the Physics Department, this paper was printed in full.*

An outstanding feature of Popov's published works is his thorough knowledge of the literature on the given problem. All Popov's works show that the author attempted to build up a historical background for the topic under consideration. And this is also true of the above-mentioned report. After an acquaintance with the literature, the author found that as early as the first half of the 19th century scientists, and among them Faraday and Seebeck (the inventor of the thermoelement), had investigated the sounds of heated metal. Popov, however, pointed out that the physicists had interpreted this phenomenon in terms

* *Journal of the Russian Physical and Chemical Society*, 1894, Vol. XXVI, Physics Department, Section one, Vol. 9, pp. 331-334.

of acoustics. However, with the development of electricity, for example, of telephony, these phenomena are viewed, "of course, in another light, as a case of the transformation of heat energy into the mechanical energy of sound oscillations, and even (given favourable conditions) into the energy of visible motion."* This conclusion Popov confirmed by experiment.

Popov's work dealing with the transformation of heat energy into mechanical energy completes the period of his activities that preceded the invention of radio. It was received as an outstanding phenomenon in the scientific life of Kronstadt. Popov also spoke on the transformation of heat energy into mechanical energy in the Physics Society in St. Petersburg.

Popov's successes in the fields of teaching and science arrested the attention of the higher naval officers and he very soon became a prominent figure in the Naval Department. Georgiyevsky pointed out that "not a single important problem connected in one way or another with the fields of physics, especially electricity, was handled in the Naval Department without the participation of Popov. This rapid rise as an authority in the Navy was to be explained not only by his extensive training and considerable theoretical knowledge, but also by Popov's engaging personality and the careful attention he gave to the problems that he dealt with, as well as his solution of these problems."**

Popov's participation in solving practical problems greatly influenced his research work, stimulating new ideas. Rybkin relates the following in his book *Ten Years with the Inventor of Radio*: "At one time it was found that the wiring along the continuous metal side of the ship was not reliable. The naval electricians began to notice sparks in places where they were least expected. These sparks often spoiled the insulation and on board

* *Ibid.*, p. 332.

** *Electricity*, 1925, No 4, p. 212.

the ship produced a so-called 'side tilt.' Popov began an investigation of this interesting and urgent problem of the Navy. While investigating the causes of these electric sparks, Popov came in contact with the little-investigated phenomenon of the oscillations of high-frequency currents. He found that the reason for the insulation spoiling was overvoltage, which apparently originated in the given section due to resonance phenomena in the circuit. Popov became so engrossed in the study of high-frequency oscillations that the case with the 'side tilt' soon became only the beginning of a remarkable series of works, which later led to the invention of the wireless telegraph."

Popov lectured not only in Kronstadt but also in St. Petersburg. Interest in his lectures was so great that the Chairman of the Technical Committee of the Navy and the Chief Torpedo Inspector asked the Manager of the Ministry of the Navy to organize a series of lectures to be delivered by Popov at the Naval Museum in St. Petersburg. As we have seen, the ground was already well prepared in this respect. The Navy, and especially its technical branch, had a large number of intellectuals with a good technical education who were interested not only in highly specialized problems, but who were eager to hear of every new development in the world of science.

It may be that in this respect it was Popov's lectures that were most characteristic, because the topics seemed quite removed from the affairs of the Navy. Indeed, how else can we explain the success of such a subject as "The Latest Investigations in the Relation Between Light and Electric Phenomena," if it is not simply a question of interest in topical scientific problems. The discussion was around Heinrich Hertz' investigations that were then attracting the attention of physicists throughout the world. Apparently this was understood in the Naval Department. The above-mentioned request read: "The experiments carried out by the German professor Hertz proving the identity of electrical and light phenomena are of great interest not only in a strictly scientific sense but also for elucidating problems of electrical engineering. At the present time Candidate of the University Popov is delivering lectures at the Torpedo School and has repeated Hertz' experiments. In view of the fact that it is difficult for the officers serving in St. Petersburg to attend these lectures, it would be desirable to have the lectures and experiments of Mr. Popov repeated in the Naval Museum. However, since these lectures require the transportation of rather bulky and delicate instruments as well as certain preparatory work, the Technical Committee of the Navy has the honour of appealing to Your Excellency to request that it be found possible to ask Mr. Popov to deliver lectures on the above-mentioned subject in the Naval Museum and to allocate sixty rubles to cover transportation expenses of the necessary instruments to St. Petersburg." This request was granted, and on March 22, 1890, Popov delivered in the Naval Museum a lecture entitled "On Electric Oscillations," one of a whole series which he delivered to the torpedo and other officers in Kronstadt.

Thus, problems relating to the early history of radio were the subject of close attention in the Navy a long time before the idea originated of the possibility of transmitting signals without wires. This contribution is undoubtedly Popov's. *The Materials on the History of the Torpedo School* give us an idea of the importance and popularity of Popov's lectures. These *Materials*, given in chronological order, note year after year Popov's numerous lectures and they point out that the lectures "merit special attention." One may gauge the interest shown by the naval officers from the fact that the head of the school reported to the Headquarters of the Port of Kronstadt concerning these lectures. One such report, dated February 13, 1890, reads: "During Lent the Torpedo School will offer lectures to be delivered by instructor A. S. Popov on Fridays at 6.30 p.m. The course is entitled 'Progress of Electromagnetism in Theory and Practical Applications During Recent Years.' I call the attention of the Headquarters of the Port of Kronstadt to the fact that the outline of each lecture will be presented later."

Of this cycle of lectures, the topic concerning the relation between light and electrical phenomena is directly connected with the invention of radio. It will be dealt with in more detail in the chapter devoted to Popov's investigations that led to his great discovery. The lectures that Popov delivered in 1890 are characteristic in still another way. They portray a physicist with broad interests and also a competent electrical engineer. He was equally alert to progress in the theory of electricity and in its application. The contents of Popov's lectures may be obtained only in the brief outlines of some of his reports to be found in the documents of the Central State Archives of the Navy. But from the lecture that was published (it will be dealt with in the next chapter) it may be seen that the author was well acquainted with the special literature published in other countries.

Popov's literary activities require special attention. Usually, a bibliographical list of the works of a scientist gives a rather full picture of his creative activities. This is not so with Popov. Popov's contemporaries pointed out a peculiarity of his, which resulted in many of his achievements as a scientist remaining in the background. Professor Petrovsky, in his speech in 1906 dedicated to the memory of the inventor of radio, said: "Under the influence of some daring idea expressed by Popov I had occasion to ask him whether he intended to develop this idea in one of the special journals, and the answer was invariably the same: 'Why yes, of course, but I can't seem to find the time.'" Georgiyevsky had the following to say: "Popov very rarely published his works in the form of articles and notes in the journals." His extreme modesty may be seen from the very insignificant title he gave to his truly historic lecture. Undoubtedly, there was also the fear, common to all genuine scientists, of self-advertisement.

Thus, the list of Popov's published works is very small, although he began to write early.

Popov's first published work, *Optimal Operation Conditions of a Dynamo*, was the result of extensive work in electrical engineering, which he accomplished while still a student. It must be recalled at this point that the dynamo, in the proper sense of the word, i.e., in the form it was given by the invention of the circular, and then later cylindrical, armature, was hardly ten years old, and its theory was far from being completely elaborated. It was expected that the *Electricity* journal (the only journal at that time that dealt with electrical problems) would soon carry other articles by the young author, all the more so since, as Petrovsky puts it, in this article "everything spoke of remarkable capabilities: the clearly defined practical trend of thought, the clear and definite statement of the problem, the concise and simple method of solution, and the vivid and gracefully presented results." But during some ten years only two or three new papers were published, and of them one was devoted to problems of teaching methods (the syllabus of the revision lecture course on differential and integral calculus which he compiled in the Torpedo School; these lectures were at the beginning a part of his duties at the school).

However, this small number of published papers did not prevent him from becoming recognized as a scientist. Long before he became famous through his investigations in the field of electrical oscillations, he had participated in various scientific enterprises. Two examples will suffice. In 1887 he was a member of an expedition sent to observe the total solar eclipse, and in 1893 he was a delegate to the World Exhibition in Chicago. Both events contributed much to his development as a scientist.

It may seem strange that Popov, a physicist and electrician, should participate in an expedition that has to do with astronomy. However, a closer acquaintance with the materials of the expedition of 1887 shows that it dealt not only with astronomy but was a matter of interest to the whole scientific world of Russia. Physicists took an especially active part in it since a solar eclipse offers rare possibilities for physical observations. The total solar eclipse that took place in August 1887 was an outstanding event in the history of Russian science; it was the beginning, in Russia, of a systematic study of solar eclipses.

The zone of the 1887 eclipse extended across the whole of Russia providing possibilities for a large number of observations. The Russian Physical and Chemical Society took upon itself the organization of a number of expeditions that were sent to different points in European and Asiatic Russia. Yegorov* was appointed chief organizer of the expeditions by the Russian Physical and Chemical Society.

He proposed to include as members of the expeditions not only certain cadets, he also invited former students, who after graduation from the University had kept in

* Nikolai Yegorov (1842-1919) was professor of physics at the Military Medical Academy, lecturer at the St. Petersburg University, and President of the Chamber of Measures and Weights (at this post he succeeded Mendeleyev). He took an active part in the introduction of the metric system in Russia. It was under his supervision that in 1918 the main clauses of the decree of the Soviet Government were worked out concerning the obligatory introduction of this system. Yegorov worked in electricity, optics and astrophysics. He was one of the first to begin a study of electromagnetic waves as soon as Hertz' memoirs were published, and he demonstrated in Russia and in France the results obtained. Although Popov did not study directly under Yegorov (during Popov's student years, Yegorov was professor at Warsaw University), the latter belongs to the generation of his teachers. As Chairman of the Sixth Department of the Russian Technical Society, Yegorov was active in the struggle for a recognition of Popov's rights.

contact with the laboratory of physics and who were active members of the Russian Physical and Chemical Society. And Popov was among them.

The Physical and Chemical Society took it upon itself to make known to the whole scientific world the materials obtained. The results of the work of the expeditions were published in a detailed report in a special edition of the journal of this Society.

Despite the very limited funds (the compiler of the report emphasizes the financial difficulties they were in), the Society was able to organize a series of observation stations from Vilno (Lithuania) to the Bay of Posiet on the Pacific. Popov was a member of one of the most distant expeditions that was sent to Krasnoyarsk.

Our information about this expedition, especially about Popov's participation in it, is not limited only to official materials published by the Russian Physical and Chemical Society. There are other records, including the extremely important notes of Shatelen.

After a long and thorough preparation, the expedition was sent to Krasnoyarsk. At that time, the Trans-Siberian railway line had not yet been built, and the journey lasted four weeks. The expedition went by train from St. Petersburg to Nizhny Novgorod, then up the Volga and the Kama to Perm. Then again by railway to Tyumen, by steamboat to Tomsk, and finally by horses to Krasnoyarsk. Here the expedition stayed only one month. Thus, altogether the trip lasted about three months.

The expedition of 1887 was an experience for Popov in broad scientific undertakings. The next step in this direction was made in 1893 when he was sent to the Chicago World Exhibition. At that same time, the Third International Electrical Congress, presided over by Helmholtz, was taking place in Chicago. The congress adopted a number of resolutions having to do with electrical measures. The international ampere was accepted as the unit of current. It was based on the method, suggested earlier by Academician Yakobi, of determining the magnitude of the current according to the quantity of silver which is precipitated from a solution of silver nitrate.

Popov was sent to the Chicago Exhibition as a representative of the Torpedo School "to inspect and study things in the field of electricity."

Popov's visit to the Exhibition was of great value to him. Before, he had kept close watch of new developments in the world of electricity, but chiefly through publications. There was now the possibility of becoming acquainted with the best types of electric machines and instruments, with the latest achievements in electrical engineering. By that time, the generation, distribution and consumption of electric power had reached such a level that one could speak of the advent of the age of electricity.

While in the U.S.A., Popov visited other places (besides the Exhibition in Chicago) where there was a possibility of learning about developments in the field of electricity. Several days after his arrival in Chicago he wrote home as follows: "In New York I shall probably almost get to see Edison's laboratory. Maybe I shall travel down to Philadelphia where there is also a big electric company. Today I'm going to the University and the Institute of Electrical Engineering."

The Russian press quickly reacted to such an important scientific event as was the Chicago Exhibition. The official Russian representative, Kirpichov, who had been sent to the Exhibition by the Ministry of Finance as an expert to study industry in the U.S.A., reported his findings. The *Electricity* journal carried many articles and reports on the Exhibition and the Congress. Scientific societies showed a great interest in the Exhibition, organizing sessions at which participants in the Exhibition, and among them Popov, delivered special lectures.

Popov's observations were the subject of lectures at the Naval Officers' Club in Kronstadt and in the Physical and Chemical Society in St. Petersburg. In the Physics Section of the Society, on October 12, 1893, he gave the St. Petersburg physicists a detailed description of the "teleautograph" (the prototype of the present-day phototelegraph) on show at the Exhibition.

In Kronstadt Popov was one of the organizers (in 1894) of a branch of the Russian Technical Society with which he had been closely connected since his student years.

At the very first meeting (March 18, 1894) of the organizers of the Kronstadt branch, Popov was elected deputy chairman.

Popov's association with Rybkin (he was appointed Popov's assistant in place of Georgiyevsky) began in 1894. Rybkin remained Popov's closest assistant during all the years of the latter's stay in Kronstadt. He was a graduate of the same University, the same faculty, and the same department as Popov. Unlike Georgiyevsky, whose scientific interests were connected chiefly with heat, Rybkin was engaged in the same problems as his supervisor and gave him constant aid, which was especially useful when installation of radio apparatus on the ships of the Baltic and the Black Sea fleets was begun. Popov always named Rybkin when he had occasion to mention his invention.*

The financial position of scientists in tsarist Russia was far from being brilliant. A professor who lived only on his salary was very often in need. The only way out was to get additional work (there could be no question of a literary income, because scientific papers were not

* Rybkin's pedagogical activities, which were conducted in the Navy over a period of several decades, were very important. He did not leave the Navy even during the Great Patriotic War (1941-1945), remaining in Kronstadt, where he had lived nearly 60 years, through the most difficult time of the blockade.

paid for; often the authors themselves had to publish their works at their own expense). From the very beginning of his career Popov had to do extra outside work He taught in the Kronstadt Naval Technical School (now the Higher Naval School of Engineering named after Dzerzhinsky). Despite the fact that his social and scientific position improved all the time, it did not give Popov a prosperity that would relieve him of extra outside work. During ten years (from 1889 to 1899) Popov was forced to spend his summer vacation in Nizhny Novgorod, where during the annual fair he was in charge of the electric station. Popov's remuneration here was several times his ordinary salary. Four months of work in Nizhny Novgorod gave him 2,500 rubles, whereas at school his salary was 100 rubles per month.

We must note here that Popov's interest in the power station at Nizhny Novgorod was not due solely to his need of money. The main thing was that here he had the possibility of working as a practical electrical engineer in the broad sense of the word. Popov's supervision of the station at the fair aided in making it a model unit equipped with up-to-date machines and instruments, the latest developments in electrical engineering.

The press of that time reported on Popov's work at the Nizhny Novgorod station, and it was called to memory many years later. In 1925, when the U.S.S.R. celebrated the 30th anniversary of radio, some of Popov's co-workers were still working in Nizhny Novgorod. Their recollections were taken down and published in the journal *Telegraphy and Telephony Without Wires*. Below are a few excerpts from these notes.

"Three of Popov's contemporaries are still working at the electric station in Nizhny Novgorod: Matveyev, Cherkasov, and Ruseikin; the latter, who came to the station 30 years ago in 1895, gave some facts about the inventor.

"Popov had a small study at the station which was located near the Betankursk canal on the corner of Pushnaya and Pervaya Sibirskaya streets. His family lived in Rastyapino where they had a cottage. Ruseikin and Matveyev recall that Popov was a very plain, kind-hearted man who never refused to explain to the workers any technical or administrative difficulty. Many who knew of his kindness and hospitality used his influence with the owners of the company, and received from Popov help in matters that were not directly connected with him."

Speaking of Popov as an electrician we must dwell on the considerable work that he accomplished in Perm (the capital of the Gubernia, now Molotov). Popov never forgot his home town, and the places where he spent his childhood and youth. Popov had a passion for photography, and in his archives there are a large number of photos of his home countryside, which he often visited even when he was extremely busy with scientific work and teaching.

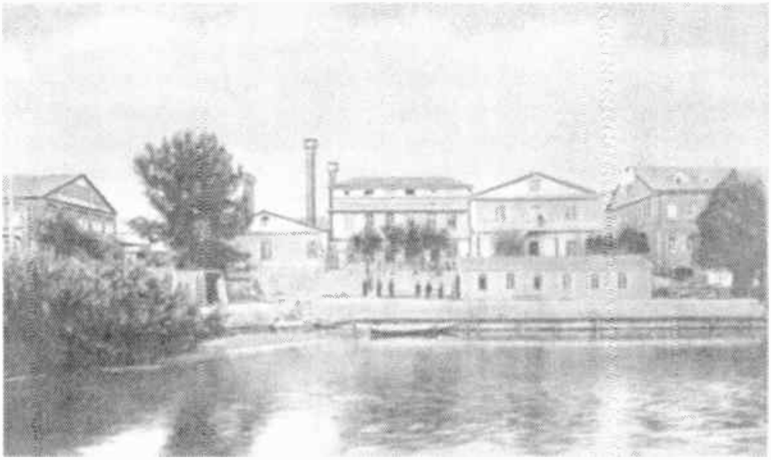
Twenty-five years after Popov finished the seminary and had left Perm he took an active part in installing electric lighting in the town. When the municipal authorities announced their decision to install a system of electric lighting, a large number of competing firms were eager to offer their services. This profitable order was sought for by Schukkert, Ericsson, Union, Volta, Siemens, Helios, and the General Electric Company, who were not slow in presenting their projects. In order to make order out of this flow of proposals, it was decided to appeal to their famous countryman, whose activities were already well known. This was in 1900. Popov immediately accepted the proposal and carefully considered all the projects, appending a lengthy memorandum which came out in Perm in a separate edition. The *Memorandum to the Projects of Electric Lighting in the Town of Perm* is a document of considerable interest.

The problem that confronted Popov was not so much one of selecting a firm; it was more a question of selecting the type of current to be used. By that time, the advantages of alternating current had already been well established, and when it was a question of long-distance transmission, everything was in favour of using alternators and not dynamos.* As we know, the struggle between these two systems was long and tense; among the supporters of direct current were not only the representatives of firms that handled such equipment, but also prominent scientific authorities. Some of them were directly connected with the firms, others simply found it difficult to part with the established, though obviously out-of-date traditions. It must be said that during the first period of electricity, alternating current had advantages only in the case of long-distance transmission. In short-distance transmission, direct current was undoubtedly profitable economically. The transmission distance from the central power station in Perm was not very great, but Popov approached the problem in a broader way paying careful attention to every detail.

Popov wrote as follows in his memorandum: "The first problem is that of selecting a system of lighting based on either high-voltage direct current or high-voltage alternating current. Experience in lighting towns shows that direct current is to be preferred for distances not greater than one verst (3,500 ft.) from the station because the outlay on equipment is less. For cases when the district to be lighted lies at a distance greater than one verst from the station, alternating current is preferable with respect to initial outlay on equipment, the preference growing with the distance. The system of lighting in the town of Perm lies half way between these limits and therefore it is difficult to decide which system should be used, all the more so since it has become possible lately to employ a relatively high direct-current voltage."

* These were the terms then used to distinguish between A.C. and D.C. motors.

P. N. Rybkin (1894)



The electric station at Nizhny Novgorod. It was here that Popov first made practical use of his storm indicator

The Torpedo School in Kronstadt

After carefully weighing all the advantages and disadvantages of both systems, Popov noted that he did not find "a decisive advantage of one system over the other." However he considered it his duty to point out that one should not be guided by economic considerations alone in building public utility stations; the interests of the consumer should be at the forefront. He added that "aside from the economic aspect of the question of using a given system of lighting, certain other considerations should be borne in mind. First of all, there is the question of uninterrupted lighting which depends chiefly on possible fault in the motors. From this viewpoint, the design of alternating current motors is more durable and reliable. The same may be said also of alternating current conductors. Besides this, lighting in a system of alternating current can be conveniently divided into a larger number of transformers, and as a result, possible damage to wires will influence a smaller number of consumers, causing less inconvenience and displeasure."

In addition to the memorandum, Popov calculated the cost of lighting, and drew up a short cost list of individual items of the equipment and also a list of the apparatus required for the power station and the electric lighting. Popov also gave his written opinion not only on questions directly connected with his special line (electrical engineering). The station was of the steam-type and so Popov had to deal with heat engineering, with which he was well acquainted because the Nizhny Novgorod station was also a steam power station.

CHAPTER THREE

THE INVENTION OF RADIO

On the Way to the Great Discovery

May 7 (April 25, old style) 1895 is considered to be the date of the invention of radio.* It was on this day that Popov read a paper in the Physics Department of the Russian Physical and Chemical Society entitled, *On the Relation of Metal Powders to Electric Oscillations*. However, Popov arrived at his discovery much earlier; not at once, of course, but as a result of extensive research which he had conducted over a period of several years studying electric waves and oscillations. The May 7th address was a legal confirmation of Popov's right as the inventor of wireless telegraphy.

In its turn, Popov's scientific accomplishment was the culmination of the efforts of several generations of scientists, whose works make up the early history of radio which began with the investigations of Faraday.

Faraday's discovery of electromagnetic rotation and electromagnetic induction laid the foundation of present-day electrical engineering.

His natural-scientific conceptions created a revolution in the understanding of electrical phenomena, and are extremely important because they directed all attention to the medium surrounding the electrified body. Faraday's theory of magnetic and electric lines of force proved to be exceedingly fruitful, and served as a

* In the Soviet Union, May 7 is celebrated each year as Radio Day.

starting point for J. C. Maxwell to deduce mathematically (and Hertz to detect experimentally) the existence of free electric waves. Later it was found that as early as 1832 Faraday himself was close to what triumphed in science more than half a century later. A letter by Faraday to the Royal Society was published not so long ago and was accompanied by the following note on the envelope, "Original views—to be deposited (by permission) unopened for the present in the strong box of the Royal Society." The text of the letter ran as follows:

"Certain of the results of the investigations which are embodied in the two papers entitled 'Experimental Researches in Electricity,' lately read to the Royal Society,* and the views arising therefrom, in connection with other views and experiments, lead me to believe that magnetic action is progressive, and requires time, i.e., that when a magnet acts upon a distant magnet or piece of iron the influencing cause (which I may for the moment call magnetism) proceeds gradually from the magnetic bodies, and requires time for its transmission, which will probably be found to be very sensible.

"I think, also, that I see reason for supposing that electric induction (of tension) is also performed in a similar progressive way.

"I am inclined to compare the diffusion of magnetic forces from a magnetic pole, to the vibrations upon the surface of disturbed water, or those of air in the phenomena of sound, i.e., I am inclined to think the vibratory theory will apply to these phenomena, as it does to sound, and most probably to light.

"By analogy I think it may possibly apply to the phenomena of induction of electricity of tension also.

"These views I wish to work out experimentally;

* The memoirs mentioned here deal with the phenomenon of electromagnetic induction.

but as much of my time is engaged in the duties of my office, and as the experiments will therefore be prolonged, and may in their course be subject to the observation of others, I wish, by depositing this paper in the care of the Royal Society, to take possession as it were of a certain date, and so have right, if they are confirmed by experiments, to claim credit for the views at that date; at which time as far as I know no one is conscious of or can claim them but myself.

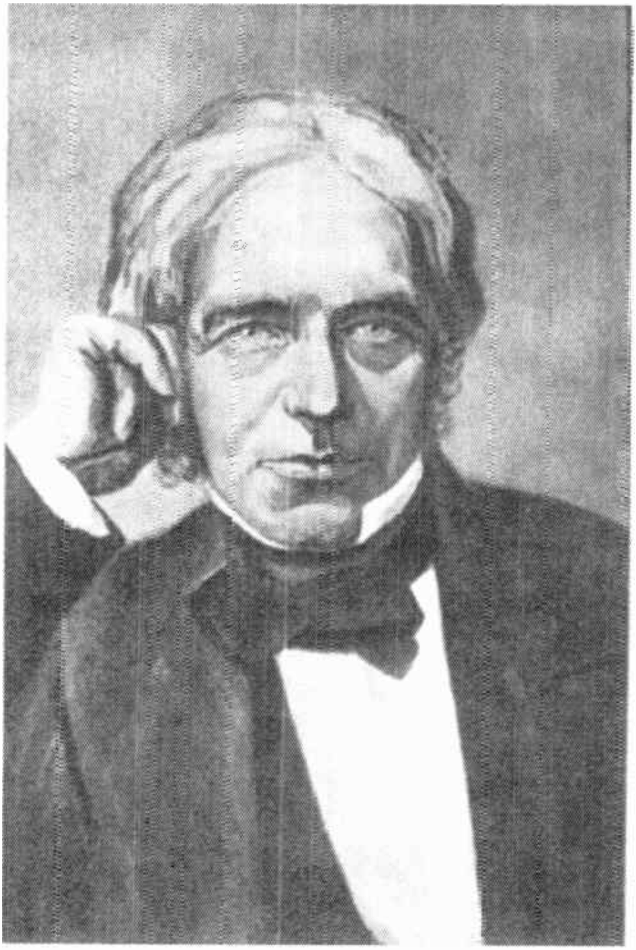
"(Signed) *M. Faraday.*"

"Royal Institution. March 12, 1832."

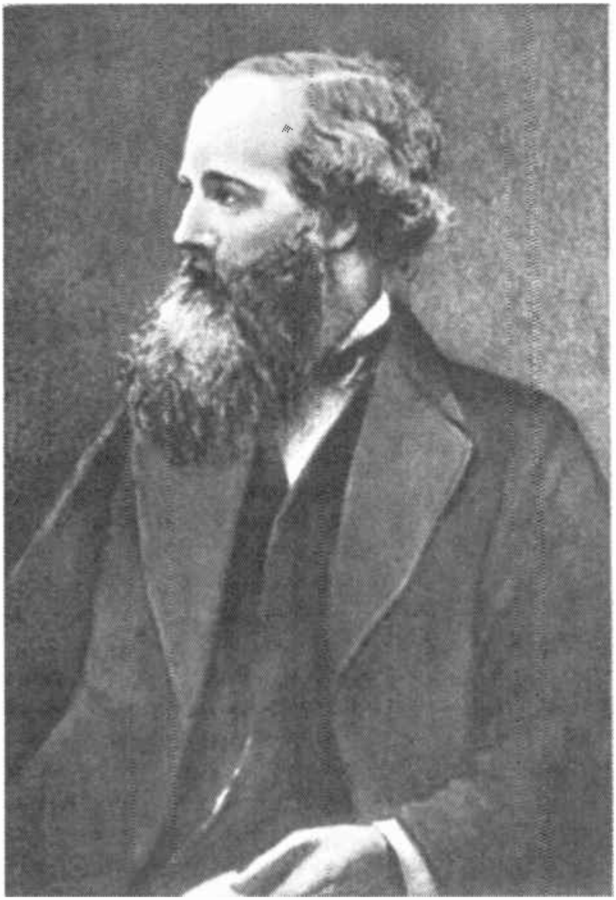
Faraday's scientific views were developed by his successor Maxwell, who worked in many fields of physics, mechanics, and even astronomy. However, his chief works are investigations in electromagnetism and in the kinetic theory of gases. Continuing Faraday's work, Maxwell subjected his ideas to mathematical treatment and arrived at far-reaching conclusions when he advanced the electromagnetic theory of light, one of the greatest achievements of science of the 19th century. Maxwell considered light to be an electromagnetic phenomenon; he predicted mathematically that electric waves ought to propagate at a velocity equal to the ratio of electromagnetic and electrostatic units; as we know, this value coincides with the velocity of light (approximately 300,000 km. a second).

Of extraordinary value to radio was Maxwell's conception of free electromagnetic waves, whose real existence was proved to the scientific world by the experimental investigations of Hertz. But this was a whole decade after the death of J. Clerk Maxwell who did not live to see his views accepted.

Deeply convinced of the truth of the Faraday-Maxwell theory, Hertz set himself the task of proving experimentally the existence of free electromagnetic waves; he



Michael Faraday (1791-1867)



James Clerk Maxwell (1831-1879)

established the fact that they are governed by the same laws (reflection, refraction, and polarization) as light waves. One of the most brilliant experimenters in the history of natural science (let us not forget that he had not yet reached the age of 37 when he died), Hertz made experiments that served as a basis for the invention of wireless telegraphy. These experiments had to do with the Hertz vibrator and resonator described in his first work entitled *Concerning Extremely Rapid Electric Oscillations.*

Originally, the vibrator consisted of two plates connected by a wire cut in the middle; at the point of the break, both wires were equipped with two small discharge balls connected with the feed source, a Rühmkorff induction coil. With this apparatus, Hertz obtained an oscillatory discharge, which he succeeded in detecting with his resonator. The latter was a metal conductor bent into a circle or rectangle so that between the ends (fitted with small balls) there remained a small gap. When the vibrator discharged, sparks jumped from one ball of the resonator to the other. The length of the sparks could be measured micrometrically. Thus, having experimentally proved the identity of the properties of electromagnetic waves and light, Hertz controlled them at will.

But nevertheless, these Hertzian waves did not go farther than his laboratory or the university garden in Bonn. His apparatus was too lacking in sensitivity for an experiment with greater distances, and not suitable at all for experiments aimed at a practical transmission of signals over considerable distances. We know that a certain engineer Huber approached Hertz in 1889 concerning this question. Hertz answered as follows:

"Dear Sir,

"It is with pleasure that I answer your kind letter of December 1.

"Magnetic lines of force propagate in a similar manner to that of rays (just as electric lines of force) only when their oscillations are sufficiently rapid. In this case, these two types of lines of force cannot be separated from each other; and the rays or waves that are discussed in my investigations could with equal right be called either magnetic or electric. But the oscillations of a transformer or telephone are much slower. Let us assume that we have 1,000 oscillations per second, which is already a rather large number of oscillations; in the ether this would correspond to a wavelength of 300 kilometres; the focal distances of reflectors that they require would have to be of the same order. If you were able to build concave reflectors the size of a continent, you would be in an excellent position to conduct the experiments you have in mind. But with ordinary reflectors nothing practical can be done, and you will not be able to detect the slightest action. At least that is what I think.

"Yours very sincerely,

"*Hertz.*"

The scientific value of Hertz' discovery, however, is not the less though he did not find a practical application for it. Hertz' discovery was immediately recognized throughout the world, and Popov was one of the first to begin elaborating further this extremely important scientific advancement. He read papers and delivered public lectures, always pointing out that this new achievement of science is not only of theoretical value, that it may find a practical application.

The path to Popov's great discovery was marked by the investigations of many scientists in different countries. Here we must dwell on the works of two of them, E. Branly (1846-1940) and O. Lodge (1851-1940).

The French physicist Edward Branly first worked in the field of medicine, electrotherapy to wit. His place in the history of radio was secured by investigations that culminated in the creation of an indicator of electromagnetic waves, which became known as the "Branly tube."

During his experiments, Branly noticed the influence of an oscillatory discharge on metal filings: the resistance of the latter fell from many thousands of ohms to several ohms due to the action of an electromagnetic wave. Branly's device, which Lodge later called "coherer," was a tube which encased two electrodes with a small space between them, this space being filled with metallic powder. The tube then is a poor conductor; however, when an electromagnetic wave passes through this device, the properties of the latter sharply change. The powder instantly becomes a good conductor.

In 1890 Branly reported to the Paris Academy of Sciences on his discovery, which incidentally had been made five years earlier by the Italian scientist F. Calzecchi-Onesti.*

In comparison with Hertz' indicator, Branly's device was a definite step forward in sensitivity but the French

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* F. Calzecchi-Onesti (1853-1922), an Italian physicist whose work in the field of electricity resulted in observations similar to those made by Branly. In 1885 Calzecchi-Onesti published an article entitled, "On the Electric Conductivity of Metal Filings." Calzecchi-Onesti's work appeared in the Italian journal *Nouvo Cimento*, 1884-1885, Vols. 16-17, but did not receive the attention it deserved. However, in Russia, for example, in the Novorossiisk University, Branly's predecessor was known, and the Russian physicist Pilchikov refers to the coherer as the Branly-Onesti tube.

We must also take note of the fact that Calzecchi-Onesti was preceded by a Swedish physicist Munk of Rosenscheld (1801-1866), professor at the University of Lunde, who half a century earlier was engaged in similar investigations and who published an article in the *Annalen der Physik* (1835, Vol. 34, pp. 437-463), entitled, "Experiments Dealing with the Ability of Solids to Conduct Electricity."

scientist likewise confined himself to laboratory investigations.

Numerous attempts were made to describe Branly as the inventor of the new means of communication, but he himself denied this, paying due respect to Popov.

The next step was made by the British scientist Oliver Joseph Lodge. He worked on problems that followed from the Faraday-Maxwell theory. Appraising correctly the work done by Branly, Lodge developed a better coherer, and using the Hertz vibrator he succeeded in transmitting waves a certain distance beyond his laboratory. It was Lodge's idea to shake the coherer so as to restore its sensitivity, which it loses due to the action of electromagnetic waves on the filings. To do this he used the clock mechanism of a Morse apparatus. If we exclude J. Ch. Bose,* Lodge was the closest of anyone to the invention of wireless telegraphy. Many years later, in 1908, when Russian scientists were engaged in a struggle for the priority of their compatriot, the Physical and Chemical Society asked the opinion of Lodge. He answered in a letter which reads as follows: "I have always thought highly of Professor Popoff's work in connexion with wireless telegraphy. It is true that I used an automatic hammer, or other vibrator driven by clockwork or other mechanism, to restore the coherer to sensitiveness; but Popoff was the first to make the signal it-

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* J. Ch. Bose (1858-1937) was an Indian physicist and plant physiologist, member of the London Royal Society, and the founder and director of a research institute in Calcutta that was named after him.

Working on electromagnetic waves, Bose constructed an instrument similar to Lodge's coherer but of an improved type which the English scientist publicly acknowledged. Although Bose succeeded in demonstrating actions that permitted one to speak of the possibility of transmitting signals over a considerable distance, he did not actually reach wireless telegraphy. A description of his coherer was published over a year after Popov's first address in the Physics Department of the Russian Physical and Chemical Society.

self actuate the tapper-back; and that I think is the novelty we owe to Popoff. . ."

Published documents and materials give the following description of Popov's work on problems of electric waves and oscillations.

Georgiyevsky, Popov's assistant in the preparation of lectures and demonstrations, says: "The first series of lectures in which I helped Popov was in 1889 and was devoted to the experiments of Hertz that interested everyone at that time. The lectures were entitled, "The Latest Investigations into the Relationship Between Light and Electrical Phenomena." The lecture programme was as follows:

"a) the conditions of the passage of an oscillating motion of electricity and the propagation of electric oscillations in conductors;

"b) the propagation of electric oscillations in the air; rays of electric force. The reflection, refraction and polarization of electric rays;

"c) actino-electric phenomena and the action of the light of a voltaic arc on electric charges."

This programme shows how profound and extensive was Popov's understanding of the problem that excited scientists the world over.

Petrovsky, Popov's pupil and successor at the Torpedo School, points out that from the very beginning of the experiments with electromagnetic waves, Popov had in view not only purely scientific aims: "Having become acquainted with the latter (the experiments of Hertz—*Auth.*), he began searching intensively for a practical application of these waves in the transmission of signals over considerable distances."

In 1894 Popov already had a rather reliably operating generator of electromagnetic oscillations. However, the receiving part did not satisfy him.**

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* *Electricity*, 1925, No. 4, p. 213.

** It is at this time that Popov wrote to his brother-in-law, the

He decided to improve the coherer and modify the receiving part to make it more sensitive and automatic in operation. To do that, Popov used a bell device for the automatic shaking of the coherer and a relay for actuating the bell. In addition, the receiver was shielded to protect it from the direct action of alternating fields.

This improved arrangement proved much more sensitive and reliable. Experimenting with it, Popov immediately succeeded in operating at a distance of several metres. He soon noticed that the operating range of his instruments increased considerably if he attached a wire to the coherer. Thus appeared the first receiving antenna. It was of fundamental importance.

Continuing to work with this arrangement, Popov noticed that it reacted to storm discharges. An instrument was soon made that reliably registered discharges at considerable distances. This was the birth of Popov's famous "storm indicator," the first radio-receiving station in the world.

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physicist Kapustin. This interesting letter, given below, describes the work of the inventor of radio during the period that preceded his famous address.

"Dear Fedya!

"While playing around with Lodge's experiments I hit upon a curious fact: in place of filings I used shot, and in the conditions used with filings it didn't conduct current at all. Believing the outer film to be the reason for the poor conductivity, I cleaned it by shaking it in the tube, the walls of which were covered with sandpaper; an exceedingly slight conductivity appeared. However, there was no action of the coherer type observed It seemed to me that the pointer of the galvanometer nevertheless moved. Look into this case carefully, although I'm almost certain that the character of the phenomena comes from the lead or its alloy with antimony That's all for now. Love to all of you, with wishes of success for you ... and for us, of course, also.

"Yours truly,

"April 16, 1895" "A. Popov."

"Kronstadt."

"This experiment requires a well-working electrophorus or a Hertzian (large) oscillator."

On April 25 (May 7, new style), 1895, the scientists, gathered at a session of the physics department of the Russian Physical and Chemical Society, made their acquaintance with the instrument that was destined to become the first apparatus for wireless telegraphy.

At first glance this was a routine session of the physics department, which, as a rule, met once a month. As usual, there were not many present. Professor Borgman of the St. Petersburg University acted as chairman in place of Petrushevsky, who was absent because of illness. The agenda contained three questions. First, Gershun reported on new books and journals acquired by the library of the department. Then Bogayevsky spoke, giving additional data to his paper on *The Law of the Parabola,* delivered at the previous session. Popov's address was third on the agenda. The minutes contained this modest note: "A. S. Popov reported *On the Relationship of Metal Powders to Electric Oscillations.*"

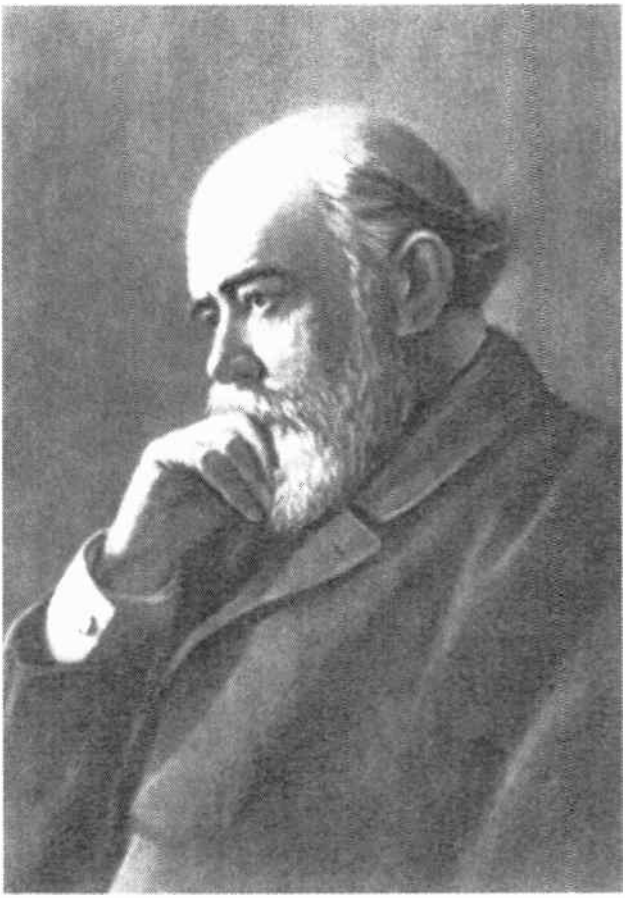
The minutes read: "Proceeding from Branly's experiments, the speaker investigated abrupt variations in resistance experienced by metal powders in the field of electric oscillations. Utilizing the high sensitivity of metal powders to extremely weak electric oscillations, the speaker constructed an instrument designed to indicate rapid oscillations of atmospheric electricity The instrument consisted of a glass tube filled with metal powder and connected in the circuit of a sensitive relay. The relay closes the current of a battery which actuates the electric bell placed in such a way that its tapper hits both the bell cup and the glass tube. When the instrument is in a field of electric oscillations or is connected with a conductor placed in the sphere of their action, the resistance of the powder decreases, the relay closes the current of the battery and actuates the bell; the very first blows of the bell on the tube restore the previous large resistance of the powder and hence again return the instrument to its previous sensitive (with respect to electric oscillations) state. Preliminary experiments conducted by the speaker with the aid of a small telephone line in the town of Kronstadt showed that the air is sometimes actually subject to rapid alterations in its potential. The speaker demonstrated the instrument just described and also the main experiments in the variation of the resistance of the powders caused by electric oscillations."

Five days later, on April 30, Popov's address was reported in the newspaper *Kronstadt Herald.* In conclusion the item read: "The occasion for all these experiments is the theoretical possibility of signalization over considerable distances without wires, similar to that of the optical telegraph, but with the aid of electric rays."

But little material still exists concerning Popov's experiments that preceded the invention of the storm indicator. Unlike many scientists, Popov apparently did not make any notes; at any rate we have no knowledge of them. This blank spot is filled by the testimony of people who were personally acquainted with the inventor and had worked for a long time in close contact with him. It is precisely this material that enables us to reconstruct the difficult and tortuous path that finally led Popov to his great discovery.

Rybkin, Popov's closest associate for a long time, came to him to work as assistant at the very time that the most intensive research began in the field of electric waves and oscillations. Rybkin, in an article entitled "Recollections about the Inventor of the Wireless Telegraph, Alexander Popov," writes the following about this period: "I still remember how excited Popov was when he showed me a copy of *The Electrician* that contained Lodge's article, in which the latter described his famous experiments in the application of Branly's discovery to the coherer device with the purpose of detecting electric oscillations. A valuable contribution had been made in a field that had occupied Popov for 10 years. Popov imme-

Heinrich Hertz (1857-1894)



Oliver Lodge (1851-1940)

diately reproduced these experiments and in the process he created his famous arrangement of the first receiving station that laid the foundation of the wireless telegraph.

"Branly showed that under the action of the discharge of a distant spark, metal filings instantly reduce their resistance to a minimum, and are thus not capable of receiving the next electric pulse. The filings must be shaken after each spark in order to restore to them this valuable property. At first Popov pasted to the pointer of the galvanometer a sheet of paper having light-weight electrodes and sprinkled iron filings over them. When a current was passed the pointer deflected considerably; this movement shook up the filings sufficiently, and they again acquired their initial resistance. The current in the circuit ceased and the pointer of the galvanometer quietly remained at zero. The next spark from the adjoining room made the pointer deflect quickly and then again return to zero. This first experiment could not satisfy Popov. The sensitivity of the arrangement was good enough but the system was too unstable. The inquisitive mind of the inventor overcame this difficulty, however. His new idea was to introduce a relay. And the results of a test exceeded all expectations. The sensitivity of reception increased perceptibly, and the accuracy was such that it became possible to register on a tape any electric pulses without a miss.

"Popov was carried away by his work and did not notice that time was flying and there would be very little left before the summer vacations and his departure for Nizhny Novgorod, where he was in charge of the electric station. It was time to sum up his experiments. To do this, Popov climbed to the top of the arbour in the garden at the Torpedo School in Kronstadt and from this point sent up on a tiny balloon a slender copper wire, the end of which he attached to his receiving station. The slightest variation in the altitude of the balloon changed the electric potential at the end of the receiving wire, and the receiving station made note of this by a clear ringing of the bell. Popov continued these experiments and was able to mark the approach of lightning discharges up to a distance of 30 versts. Popov gave his storm indicator to Professor G. A. Lyuboslavsky of the Institute of Forestry for tests during the coming summer."

Only after his return from Nizhny Novgorod could Popov bring to a close his lengthy investigations. They are described in an article entitled, "An Instrument for Detecting and Registering Electric Oscillations." The article is dated December, 1895. It gives a vivid picture of his arrangement. "A tube with filings is suspended horizontally between clamps M and N from a light watch spring, which on the side of one of the clamps is bent into a zigzag to produce greater elasticity. Above the tube is a bell placed in such a way that it can strike the middle of the tube lightly with its tapper. The tube is protected by a rubber ring. It is most convenient to attach the tube and bell on a single vertical board. The relay may be placed as desired.

"The instrument works as follows. The battery current (4 to 5 volts) circulates constantly from clamp P to the platinum plate A, from that through the powder in the tube to the other plate B and along the winding of the electromagnet of the relay back to the battery. This current is not strong enough to attract the armature of the relay, but if the tube AB is acted upon by an electric oscillation the resistance will instantly be reduced and the current increased to such an extent that the armature of the relay will be attracted. At this point the circuit from the battery to the bell, interrupted at C, will be closed and the bell will begin to operate, but the shaking of the tube will again immediately reduce its conductivity, and the relay will disconnect the bell circuit. In my instrument, the resistance of the filings after a strong shaking is close to 100,000 ohms, and the relay with a resistance of about 250 ohms attracts the armature at currents of 5 to 10 milliamperes (the control limits), i.e., when the resistance of the whole circuit falls below a thousand ohms. To a single oscillation the instrument responds with a brief ring; continuous discharges of the spiral are noted by rather frequent rings that follow one after the other at approximately equal intervals."*

Thus, Popov succeeded in building a sensitive receiver that successfully detected and registered electric oscillations, true, as yet only in the atmosphere. But even as such, Popov's invention found practical application in meteorology. His instrument was set up in the Institute of Forestry (in St. Petersburg) and reacted readily to lightning discharges at distances up to 30 km.

Over half a year elapsed between Popov's address in the Physical and Chemical Society and its publication. As Rybkin pointed out, the investigator was not in a position to prepare his report for print. Nevertheless, Popov's discovery became known to the broadest scientific circles. The essence of this discovery is described in the minutes that were published in the journal of the Society the same year. Popov's address was published in full in 1896, first in the January issue of *The Journal of the Russian Physical and Chemical Society,* and afterwards also in other publications (*The Meteorological Herald* and *Electricity*).

However, Popov's achievements were known before this and not only in narrow scientific circles. Already as early as 1895, Popov's works began to find their way into textbooks. That year saw the appearance of the second edition of *The Principles of Meteorology and Climatology*, a fundamental work by Lachinov.**

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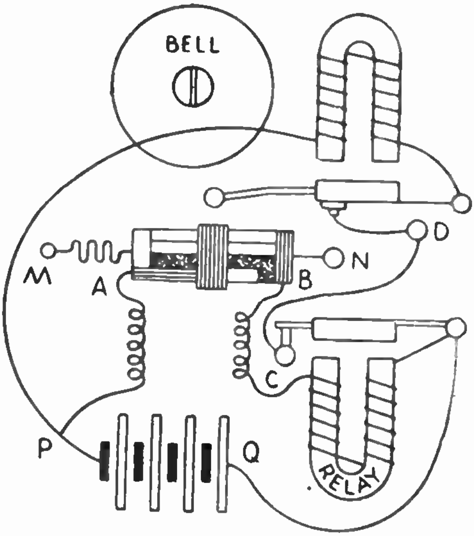
* *The Journal of the Russian Physical and Chemical Society,* 1896, Vol. XXVIII, Physics Department, Section one, Vol. 1, pp. 7-9.

** Dmitry Lachinov (1842-1902) was honoured professor of the St. Petersburg Institute of Forestry (now the Kirov Technical For-



Circuit diagram of Popov's storm indicator

In the chapter on "Atmospheric Electricity," there was a special section entitled, "Popov's Discharge Indicator."

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estry Academy), and a graduate of the same University that Popov finished. He was a physicist, meteorologist and electrical engineer. His works devoted to problems of the theory of the transmission of electric energy are especially well known.

A prominent member of scientific societies (the Physical and Chemical Society, the Technical Society, in which he was one of the founders of the Sixth Department, and the Meteorological Commission of the Geographical Society), Lachinov repeatedly represented the Russian scientific public abroad, constantly popularizing the achievements of Russian scientists and inventors. Lachinov did much to make Popov's invention known. Already in 1895 Popov's apparatus found its first practical application in the Meteorological Observatory of the Institute of Forestry, which fact was noted by Popov in the very first publication concerning the invention.

It was Lachinov's idea to use wireless telegraphy for broadcasting.

Guglielmo Marconi (1874-1937)

Jagadis Chandra Bose (1858-1937)

The Fight for Recognition

The history of engineering shows how few were the inventors of the 19th century who did not have to speak in defence of their rights. Frequently, the fight for priority pursued commercial aims, since a patent for any important invention brought huge profits. This explains the endless lawsuits between individuals in the attempt to prove their rights.

In the electrical field this fight was probably the sharpest. It is hard to name a single big invention that was not the subject of argument, or, often, of a court case between electrical inventors claiming priority for a new idea. Lawsuits were so frequent (especially in the U.S.A.) during the second half of the last century that they were considered a common event.

Such a profit-making approach to the attainments of the applied sciences could not but be repulsive to the best scientific circles. Indeed, the most outstanding workers in electricity in the 19th century did not make their discoveries a source of profit. Neither Faraday, nor Henry, nor Lenz, nor Yakobi, nor Hertz were holders of patents that brought them profits.

Popov, who was brought up on the noble traditions of the best scientists, least of all thought to obtain a patent for his invention. As soon as his apparatus took on a technically finished form, he did not take it to the Department of Trade and Industry of the Ministry of Finance that handled patents in Russia, but to the Physics Department of the Russian Physical and Chemical Society. And when it was found that this apparatus could be of practical use in meteorology, he addressed a joint session of the Russian Geographical Society and the members of the Chief Geophysical Observatory, and demonstrated his storm indicator.

Both of Popov's reports were published in the journals* of the societies, and the rights of the inventor of radio were thus secured to him. The sensation around the Marconi patent that began abroad in 1896 and later in Russia caused indignation in informed scientific circles, which took the proper measures.

Popov's first reaction was at the beginning of January 1897. On the 8th of January, the Kronstadt newspaper *Kotlin* published a letter by Popov entitled, "Telegraphy Without Wires," in answer to an item which appeared in No. 3 of this newspaper, concerning the work of the Indian physicist Bose, who had played his part in the early history of radio. Bose's investigations as well as the works of all scientists who had made valuable contributions to the theory of electromagnetic waves evoked great interest, which increased as new sensational reports appeared in the press concerning the transmission of signals by Marconi. The *Kotlin* newspaper frequently reported scientific news, and it published an item about Bose's experiments which were carried out at about the same time as Popov's investigations. But Bose did not reach the stage of wireless telegraphy. In this case the newspaper availed itself of second-hand data, which could not but lead to an obvious misunderstanding. It was felt that the author of the report did not know the difference between electromagnetic waves and X-rays. However, it was not this circumstance that caused Popov to take up his pen. The chief reason was that the report infringed on his interests, for everything that it carried as something new had already long before been done and exceeded by far by Popov himself, which fact he proved with irrefutable data that had been published much earlier.

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* *The Journal of the Russian Physical and Chemical Society*, 1896, Vol. XXVIII, Physics Department, Section one, Vol. I, pp. 1-14. *The Meteorological Herald*, published by the Mathematics and Physics Departments of the Russian Geographical Society, 1896, Vol. VI, No. 3, pp. 61-67.

Although limited by the possibilities of a provincial newspaper, Popov nevertheless dealt in rather considerable detail with the reports that had appeared in the scientific-technical and general press and that had anything to do with the invention of wireless telegraphy. Popov points out that excited interest in these works was caused by the statement of the chief engineer of the British telegraphs W. Preece* at the Congress of the British Association for Advancement of Science to the effect that the Italian Marconi, who had recently arrived in England, had brought with him an apparatus which could transmit signals without wires. Preece delivered another lecture in the Electrotechnical Society; it was not published but it was reported in the press, and not only in England. These reports pointed out that during his lecture, Preece demonstrated experiments with the Marconi apparatus but did not disclose its construction.

As for Bose's work, Popov knew of it from original sources. He read carefully both the general and spe-

* Preece was well known as an electrical engineer; his scientific career he began in the London Royal Institute under the guidance of Faraday; in 1882, fifteen years before he met Marconi, he was elected member of the Royal Society. In the early history of radio, Preece is known for his method of transmitting signals without wires by using not electric oscillations but the action of parallel conductors; he reported on this fact at the Third International Electrical Congress, in which Popov also participated. When touching on the question of the early history of radio, Popov always pointed to the method used by Preece. Thus, at the Fourth Congress of Railway Electrical Engineers (it will be dealt with in detail below) Popov said: "The method is based on the mutual action of parallel conductors. It was accomplished by Preece, who was led to these experiments by the fact that interrupted telegraph currents even in a distant conductor give rise to such strong induction currents that it is possible to hear the action of the telegraph in the earphones. Preece attempted to utilize this in practice, and at the Chicago Congress he reported on the results achieved."

cial literature, having at his disposal the rich library of the Torpedo School. which always received new books and also all the electrical journals of the slightest importance. In his letter Popov referred to the real facts, giving a true picture of the state of affairs, which was as follows: "The October issues of the British journal *Nature*," wrote Popov, "carry the reports of the sessions of the British Association. Bose's instrument for the study of electric waves* was demonstrated at one of these sessions. In this connection, Preece reported on the experiments with Marconi's instrument, conducted by the British telegraph agency, with the well-known telegraph engineer Kempe participating. The experiments in transmitting signals with the aid of Hertzian electric waves took place on the broad territory of Salisbury Plain and reached a distance of $1^1/_4$ miles; in addition, he mentioned experiments conducted on separate hills without indicating the distance.

"Bose's instrument was described in the London journal *The Electrician* in October of this year. The instrument was a modification of the same as Lodge's, which was demonstrated as early as 1894. Lodge himself was present at this session and he agreed that Professor Bose's instrument was more compact and steady in operation in comparison with his own."

After giving a description of Bose's apparatus from material found in the scientific literature, Popov wrote: "In 1895 I built a similar instrument based on the same principle. In April that instrument was demonstrated at a session of the Physics Department of the Russian Physical and Chemical Society and at a special meeting of meteorologists since my instrument may serve for registration of electric vibrations that are present in the atmosphere during thunderstorms, and also of weak electric disturbances that occur in winter time."

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* *Nature*, 1896, Vol. 54, No. 1046, Oct. 8, p. 567.

In his letter, Popov pointed out that his apparatus had been in use already for more than a year at the Meteorological Station of the Institute of Forestry, and that in addition the storm indicator had been on exhibit in 1896 at the All-Russian Industrial and Art Exhibition (in the Meteorological Section) and had received a prize.

Of great interest in Popov's letter is the place that shows his broad views concerning the utilization of electromagnetic waves. It was clear to him that the apparatus he had invented could be used in many ways. "My instrument," he pointed out, "rings a bell in response to electric waves, and all the experiments described in the No. 3 issue of the *Kotlin* newspaper, such as firing a shot, setting off an explosion, etc., can be handled with it, that is, everything that is done with the energy of an electric current because in this instrument the electric wave acts on a telegraph relay, and a relay can connect up any type of outside energy."

In the item that appeared in the No. 3 issue of the *Kotlin* newspaper, it was also pointed out that this could possibly serve as a new means of communication in the Navy. This naturally was of the greatest interest to the Kronstadt newspaper. When demonstrating his storm indicator, Popov expressed the idea of using electromagnetic waves for purposes of wireless telegraphy. Although Popov was careful, as befits a research scientist, nevertheless the views he expressed, though having not a trace of sensational promises, definitely indicated the practical possibilities of using his invention in the Naval Department in the nearest future. And in doing so he pointed out the weak spots in the arrangement for the transmission of signals without wires. Popov stated that "signalization with electric rays is similar to optical and sound signalization; the signals may be directed mainly in one direction or simultaneously in all directions. Within the limits of one mile, signalization is possible even now. The eye for the electric rays is satisfactory, we must now direct our attention to the source of the electric rays; the present Hertzian vibrators are weak in comparison with sources of light. . . . Fog was not observed to act on the electric waves, but there is much that compels us to expect a considerably attenuating action on the part of fog, and therefore we may expect the application of these phenomena to be essentially useful in the Navy both as beacons and for signalization between the ships of one and the same squadron."

Circumstances were such that Popov had to come out several more times in defence of his rights. The beginning was the 8th of July, 1897, when the *St. Petersburg Gazette* published an interview with Professor Lachinov, who informed the reporter of this newspaper of the real facts that showed who the actual inventor of wireless telegraphy was. The interview was entitled, "The Russian Inventor." It was introduced by the newspaper with the following lines: "The whole civilized world recently read in the papers about the new invention of the Italian Marconi in the field of telegraphy (wireless telegraphy). The name of the young inventor immediately became known in both hemispheres, he was glorified, cheered and spoken of throughout the world and . . . all for nothing. All Russian readers who hailed the foreign invention will be not a little struck when they hear that the idea of telegraphy over great distances without the aid of wires belongs to our compatriot, a well-known scientist who discovered the new method of telegraphy as long as two years ago and who did not want to publish prematurely the results of his work because of a natural desire to bring to perfection his telegraph instrument."

The next day, July 9, the newspaper *New Times* carried the following item: "The *St. Petersburg Gazette* reports that the idea of wireless telegraphy appeared in Russia two years before the work of the Italian Marconi, and that it belongs to Professor Popov who lectures in physics in the Kronstadt Torpedo School; already two years have passed since his experiments (which are known to all his pupils and associates) were conducted. The *St. Petersburg Gazette* adds that because of a 'modesty' 'peculiar' to Professor Popov, and also because of his natural desire to bring his telegraph instrument to perfection, he did not wish to make known prematurely the results of his work.

"We may only regret such modesty, for there was no reason to be modest in a case like this, other than fear that someone else might utilize the idea that had become known."*

This latter remark could not but offend Popov, who though extremely modest, had done much to make his invention known. It had appeared in three publications: *The Journal of the Russian Physical and Chemical Society, The Meteorological Herald,* and *Electricity.* In his letter to the editors of the *New Times,* Popov reminds them that he reported on his work not only in scientific societies (twice to the Physical and Chemical Society, at a meeting of St. Petersburg meteorologists and at a session of the Kronstadt Branch of the

* The reasons for the stubborn disregard of Popov's merits on the part of the *New Times* was revealed later, after a certain I. Snessarev left the newspaper and published a book, entitled, "The Mirage of the *New Times*," in which he disclosed the dubious dealings of the paper. In connection with the appearance of this book, V. I. Lenin wrote as follows, in an article, "Capitalism and the Press": ". . . Mr. Snessarev was approached once by a representative of the Marconi Wireless Telegraph Company in London and offered to draw up a charter for a Russian Marconi Company, and a draft project for a concession in favour of this company. . . . The whole *New Times* sold itself for this 'campaign in defence of the concession,' receiving a 50 per cent cut on telegrams and a 'warm place' as constitutor of the company with shares to the sum of 50,000 rubles."

Russian Technical Society), but also in the form of a public lecture. He did not only refrain from hiding his apparatus, on the contrary, he exhibited it at the All-Russian Industrial and Art Exhibition, which, as we know, attracted to the town of Nizhny Novgorod engineers and scientists from all parts of the country and even from abroad.

Despite all the respect which Popov attempted to retain in his letter, it still is full of indignation, caused by the undue familiarity of the remark of the editors of the *New Times*. His answer to the item of this newspaper contains the following lines: "I am forced to make this letter rather long in order to avoid any such misunderstanding as that in your remark."*

Popov then lists the facts about which he wrote in his letter to the *Kotlin* newspaper, and referring to his first publication (*An Instrument for Detection and Registration of Electric Oscillations*), he points out that it ends with the words: "Concluding, I can express the hope that my instrument, after certain improvements, may be used to transmit signals over considerable distances with the aid of rapid electric oscillations as soon as a source of such oscillations having sufficient energy is found."

Half a year passed since Popov's letter appeared in the *Kotlin* newspaper. This period was replete with intensive and successful investigations in the field of the

* Popov's letter is quoted from his autograph, published by Professor Kyandsky in the journal *Socialist Reconstruction and Science* (1935, No. 5, pp. 101-102). The passage quoted was left out by the editors of the *New Times* in the text they published (July 22, 1897, No. 7686, p. 3). The editors also made other changes, which fact was remarked on by Popov in a letter dated July 24 from Nizhny Novgorod to his assistant Rybkin: "Today I received the *New Times*, which at last has my letter of July 15. They very cleverly changed the sense of the letter so that the rebuke it contained with respect to the item in the *New Times* disappeared entirely; but let them be consoled."

wireless transmission of signals. This was all stated briefly by Popov in his letter to the *New Times*, which was written a month after the publication of Marconi's arrangement,* which till then had been kept a secret. Referring to reports of Marconi's experiments, Popov then compared Marconi's arrangement with his own. "In June," he writes in his letter, "Preece published new results of Marconi's experiments as well as the details of the instruments, and it appeared that Marconi's receiver was (in its component parts) the same as my instrument, made in 1895."

Popov's letter was immediately commented on. It appeared in the August issues of the *Engineering Journal*, and *The Post and Telegraph Journal*. In addition, the journal *Electrotechnical Herald* published in its August issue an article entitled, "On Marconi's Invention," which was based on the material of Popov's letters to the *New Times*.

This was the first step taken by the Russian scientific public in defence of the rights of their compatriot. In September and October the fight spread. It was at this time (September 15) that the Fourth Congress of Railway and Other Electricians was being held in Odessa. The organizers of the Congress invited Popov, who had just returned from Nizhny Novgorod, to speak on the new, type of communication.

We still have very interesting material that deals with Popov's first address to the Russian electricians arrived from all over the country. The facts show that it was a real holiday for Russian science.

The work of the Congress was not only published in the form of minutes, it was discussed in a number of

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* Marconi's arrangement was first announced in the summary of a lecture delivered by W. Preece on June 4, 1897, at the Royal Institute in London, entitled, "The Wireless Transmisson of Signals" (*The Electrician*, 1897, June 11, Vol. XXXIX, No. 7, pp. 216-218).

periodical publications. Everywhere, Popov's report was the centre of attention, and it was pointed out to the readers that this most important achievement in the field of communications belonged to Russian science. There is also much valuable material concerning Popov's personality and about how warmly he was met by the members of the Congress and by all present during his address.

At the same time, this material shows how low the level of popularization of the achievements of Russian scientists was in tsarist Russia. Not only the broad masses of the people, but even many specialists in electricity knew nothing about Popov's work.

The chairman of the Congress, Euler (a descendant of the famous scientist Euler*), opened the session with these words: "We had hardly received the news of the work of Professor Roentgen, which is now so widely in use, when in September, 1896, there appeared the first items concerning experiments with electric waves carried out by the British telegraph agency according to Marconi's system. On the 4th of June of the current year, a detailed report** is presented, dealing with Marconi's invention for the wireless transmission of signals. We were all eagerly looking into this new advancement of man's inquisitive mind, when we found out quite

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* Alexander Euler (1861-1921) was the grandson of the son of Leonard Euler (1707-1783), Christopher (1743-1812), Major-general of artillery and Head of the Sestroretsk Armoury. An active member of the Sixth (Electrotechnical) Department of the Russian Technical Society, Euler devoted his works to problems of communication on railway transport, the last years of his life he worked on the October Railway Line as Assistant Chief of the Communication Service

At the Odessa Congress, Euler delivered a report on "Simultaneous Telegraphy and Telephony over a Single Wire" that caused much lively discussion

** Here reference is made to the above-mentioned report of Preece at the Royal Institute.

by accident that work had already been done in this field by our own honourable compatriot Popov. In 1895 and at the beginning of 1896, he constructed an instrument for the detection and registration of electric oscillations in the atmosphere; in comparison, Marconi's invention is nearly an exact copy. Thus, it appears that the famous experiments of the late Professor Hertz of Bonn University served as a cornerstone for the elaboration of a system of transmitting electric waves for purposes of signalization. And this was first done here in Russia. It is a pleasure to see Mr. Popov, who has consented to share with us his knowledge and views on the question of wireless telegraphy, and also to inform us of the results of his latest experiments, conducted at the request of the Naval Department."*

This last part of Euler's speech is very important. It is indicative and characteristic of Popov as a selfless investigator and true representative of progressive science. Popov's aim was to share his achievement with the audience, and not simply to excite their curiosity.

The report, included in the minutes of the Congress, also contained facts concerning Popov's address itself and the feelings it evoked among the members of the sitting. It reads: "Popov's communication and the demonstration of experiments continued several hours. It was listened to with great interest, the speaker was rewarded with stormy applause and was thanked for his valuable communication. The members of the Congress made note of the fact that our compatriot was the first to make use of the method of wireless telegraphy. Only one and a half years later, already after his works had been published in the specialized journals, did there appear in foreign publications a report concerning the

* Notes of the Odessa Branch of the Russian Technical Society, 1897, Vol. 7, pp. 3-4.

invention of the Italian Marconi, which produced a sensation in the technical world."*

The same warm response was given to Popov's address by the local press, which viewed this event as being of exceptional importance in the history of Russian science. Although Odessa was not a gubernia centre (it was a part of the Kherson Gubernia), it was a university town with the Novorossiisk University that occupied a prominent place among the higher educational institutions, having such eminent men of science as Sechenov, Mechnikov, Kovalevsky, and Umov. The exceeding interest that the intellectuals of the town took in all scientific news was therefore quite understandable.

The agenda of the Congress included topical problems, of importance not only to railway transport. There were questions that were of interest to all departments (both civilian and military), in which electrical equipment had found a field of application. Alongside topics that dealt with communications, as, for example, "On Simultaneous Telegraphy and Telephony over a Single Wire" or "On the Application of Lightning Rods to Telegraph Instruments," there were reports that had to do with the field of strong currents (electric lighting and electric traction). It may thus be seen that the Congress considered problems that were of great interest to a broad circle of specialists. But Popov's address evoked the greatest interest and was reported on September 18 by all the Odessa newspapers.

The central press also gave a prominent place to Popov's address in Odessa. In its report on the work of the Congress, *The Post and Telegraph Journal* wrote: "Popov told the representatives of the Congress about his work in wireless telegraphy and demonstrated the following experiment in the transmission of signals,

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* *Ibid.*, p. 5.

which was compared with a later system of the Italian Marconi. A transmitter was placed in the library of the Technical Society. In the main hall, behind a thick stone wall, was the receiver, which was invented by the speaker as early as 1895. This receiver consisted of a small glass tube with iron filings, a galvanic battery and a telegraph apparatus. When sparks appeared in the receiver, the telegraph apparatus produced signals. The thick walls did not interfere in the transmission of signals even though there were no wires at all. According to the speaker, the same action is produced if the transmitter is at a distance of two and more versts."

On his return from Odessa, Popov was greeted in the capital with still greater enthusiasm. On the initiative of the Sixth Department of the Russian Technical Society, Popov was invited to deliver several public lectures and demonstrate his experiments in wireless telegraphy. The Sixth Department of the Society, already nearly 20 years old, regularly organized lectures and reports on the most important achievements in electrical thought, and the speakers were often people who had made the latest contributions to the applied sciences. Among them we find such men as Yablochkov, Ladygin, and Chikolev.

Popov's lecture took place on October 19 in the Electrotechnical Institute and attracted a large audience. It was taken down in shorthand and soon printed, and was well received by the press.

Before Popov's lecture was published in a separate edition, it appeared in *The Electrotechnical Herald* (No. 48, 1897), with a leading article entitled, "On Popov's Invention."

Popov's lecture in the Electrotechnical Institute was of great interest in many respects. It contained valuable data on the development of his work, it described the path covered by the investigator in his attempts to solve the problem that confronted him, and also the news of his constant and intensive investigations. It was with these latter facts that Popov began his lecture. "I have come here today," he said, "straight from my work, so everything I have brought was collected in a hurry and is more in the nature of an outline experiment to explain the principles that underlie the problem of wireless telegraphy that of late has been so much talked of."

Popov was confronted with the task of explaining to the audience (consisting in part of people not sufficiently prepared) the principles that underlie the new method of communication. And the lecture was indeed comprehensible and clear to those that were introduced for the first time to electromagnetic vibrations and the possibilities of their practical application. At the same time it contained facts from the history of science which were new to many of the electrical specialists present.

Just as at the Congress of Railway Electricians, Popov demonstrated to the audience both his arrangement and Marconi's, and comparing them, said: "The arrangement of Marconi's experiments is drawn here and you can see the total identity of the component parts with those of our instrument."*

Less than two weeks after the lecture in the Electrotechnical Institute, Popov reported "On Wireless Telegraphy" in the Sixth Department of the Russian Technical Society.

Popov also came out in the foreign press in defence of his rights. In the same year 1897, *The Electrician* carried his letter, in which, referring to irrefutable facts, he continued the fight for his rights. This letter was the outcome of an article by O. Lodge, entitled, "The His-

* *The Electrotechnical Herald*, 1897, No. 48, p. 508.

tory of the Coherer Principles,"* in which the works of the Russian scientist were not mentioned.

Popov's works were studied with the greatest attention in France where his apparatus was first produced on a mass scale. Having learned of Popov's invention, engineer Ducretet asked him for permission to begin utilizing it. With Popov's permission, Ducretet not only began producing the "Popov-Ducretet" apparatus, as he called it after introducing several modifications of design, but also spoke at scientific meetings and came out in the press in defence of Popov's rights.

During 1897-1898, there appeared both in Russia and abroad sufficient material testifying to Popov's incontestable rights. Nevertheless, in 1900, at the First All-Russian Electrotechnical Congress, Popov again had to speak on the question of priority and say once more: "Was my instrument known to Marconi or not? The latter is very likely more probable. At any rate my combination of the relay, tube and electromagnetic tapper served as the basis of Marconi's first patent as a new combination of already known instruments." These words of Popov were brilliantly confirmed by a comparison of his arrangement with that published by Marconi.

The Wireless Telegraph in Action

Popov has been described in the literature as a scientist, chiefly a physicist, though not indifferent to applied knowledge.

Documentary evidence, however, gives another view of the picture. Popov was undoubtedly an original and experienced experimenter; such was the man that all his closest associates and co-workers knew. And such he remained to the end of his days. But in addition, Popov was the first radio specialist to construct radio in-

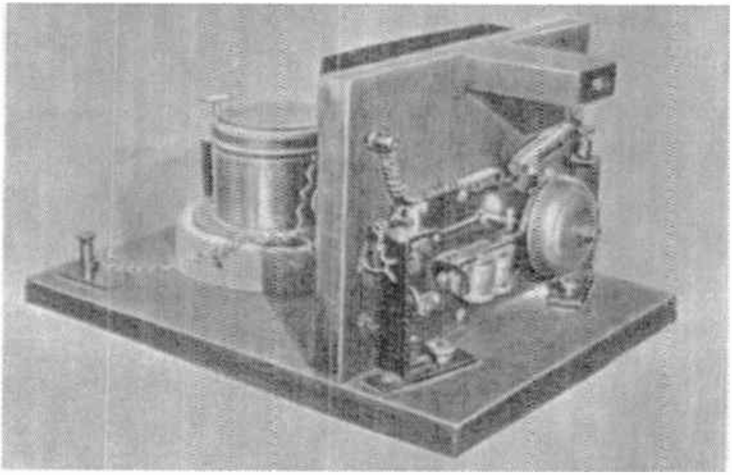
* *The Electrician*, 1897, November 12, Vol. XL, No. 3, p. 87.

struments as well as radio stations in Russia. This side of his activities was above all closely connected with the Navy, the most prominent representatives of which valued Popov especially as a practical specialist in installing radio in the Navy.

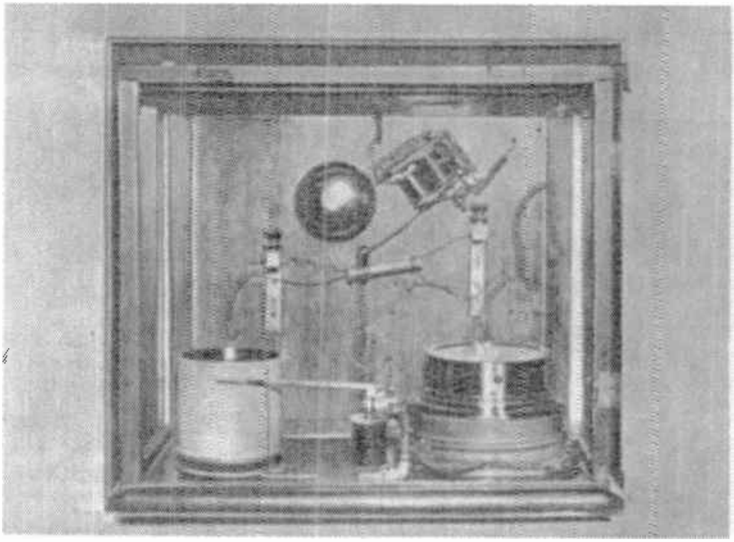
To introduce radio into the Navy would require preliminary experiments on an incomparably greater scale than those conducted by Popov in the laboratory and later in the yard of the Torpedo School. In order to begin such experiments money was needed, and no small amount either. As we shall see, Popov himself had no idea of the extent of such experiments, and put in a request for an insignificant sum. In addition, permission had to be got from the authorities to conduct experiments in wireless telegraphy at sea, at first between the ships and the shore and later between the ships themselves. To do this, it was not enough for Popov to speak in the Physical and Chemical Society and to publish material in a journal. It was a question of getting not only the scientific, but also the Naval circles interested. Popov knew this very well and from the very beginning took the proper steps.

In March 1897, he delivered a lecture at the Kronstadt Naval Officers' Club, dealing with the possibility of wireless telegraphy through the use of his method. Popov's project was well received and was approved by the higher authorities. The requested sum (which came to an insignificant 300 rubles) was allotted, and warships were placed at his disposal for the experiments. Thus, only two years after Popov made his invention did he have the possibility of expanding his laboratory investigations into large-scale experiments.

The year of 1897 was that of a considerable victory for the inventor of radio, who began experimenting on a large scale. This was noted in the report of a special commission headed by the chief of the Torpedo



Popov's storm indicator (radio receiver) demonstrated by the inventor on May 7, 1895 at a session of the Physics Department of the Russian Physical and Chemical Society



Popov's storm indicator with registering instrument

A. S. Popov (1895)

School. The report not only sheds light on the large-scale experiments in wireless telegraphy and on the attitude of the naval authorities, it also testifies to the keen interest which Russian scientists took in such experiments abroad and to the general level of Russian scientific and technical thought.

As may be seen from the report, the experiments were begun in the spring of 1897 in the Kronstadt harbour with instruments built especially for this purpose. They were installed on the cruisers *Rossiya* and *Afrika*. Signals were transmitted up to 700 metres and more. These results were exceeded several times over during the summer campaign when experiments were conducted in the Transund road of the Vyborg Bay.

Here, in the absence of Popov (he was in Nizhny Novgorod at this time, as in the preceding years) but under his constant guidance, Rybkin (assisted by torpedo man Ustinov, the watchman of the physics laboratory of the Torpedo School) conducted the experiments in accordance with instructions given to him by Popov. A high-power vibrator was set up in a special cabin on the island of Teikar-Sari; the receiver was installed on a special cutter that was sent out to sea. The greatest distance reached was three kilometres. The distance was nearly doubled when the transmitter was placed on the upper bridge of the transport ship *Yevropa*, and the receiving apparatus on the cruiser *Afrika*, where the "receiving wire" (aerial) reached a length of nearly 20 metres.

According to Rybkin, the experiments ended in the establishment of telegraphic communication between the training ship *Yevropa* and the cruiser *Afrika*. Popov was exceedingly pleased with this result. In a letter to his assistant (July 24, 1897) he wrote: "I was very much pleased with your last letter. If nothing more were achieved this year, the winter experiments would be of sufficient interest."

However, in 1897 observations were made that could be properly appraised only decades later. The above-mentioned report contains material that gives us grounds for claiming that the beginning of radar and radio navigation goes back to the experiments of 1897. This document points definitely to the scattering and reflection of electromagnetic waves from metallic objects. Here we find the following lines: "During the experiments, the cruiser *Ilyin* passed between the *Yevropa* and the *Afrika*, and if the distances happened to be big, the instruments ceased to interact until the ships got out of line again."

As we have seen, the year 1897 was marked by still another series of public speeches made by Popov. It is quite natural that now the higher naval authorities became interested in Popov's successes in the field of wireless telegraphy. On December 23, 1897, Popov repeated his lecture "On Wireless Telegraphy" for the higher officers of the Navy.

"After the lecture, a four-letter signal chosen by the Manager of the Ministry of the Navy was successfully communicated by Mr. Popov's instruments from the new building of the Chemical Laboratory situated at a distance of about 110 sazhens (1 sazhen = 7 ft.) from the lecture hall."*

The campaign of the next year, 1898, produced still better results. Actually, after the campaign of 1898, Popov considered the problem of radio communication in the Navy as solved, as may be seen from his report "On the Experiments with Wireless Telegraphy Conducted During the Campaign of 1898 in the Torpedo Detachment."

This time, regular radio communications were established between the cruiser *Afrika* and the transport ship *Yevropa*. Aside from the daily communications which

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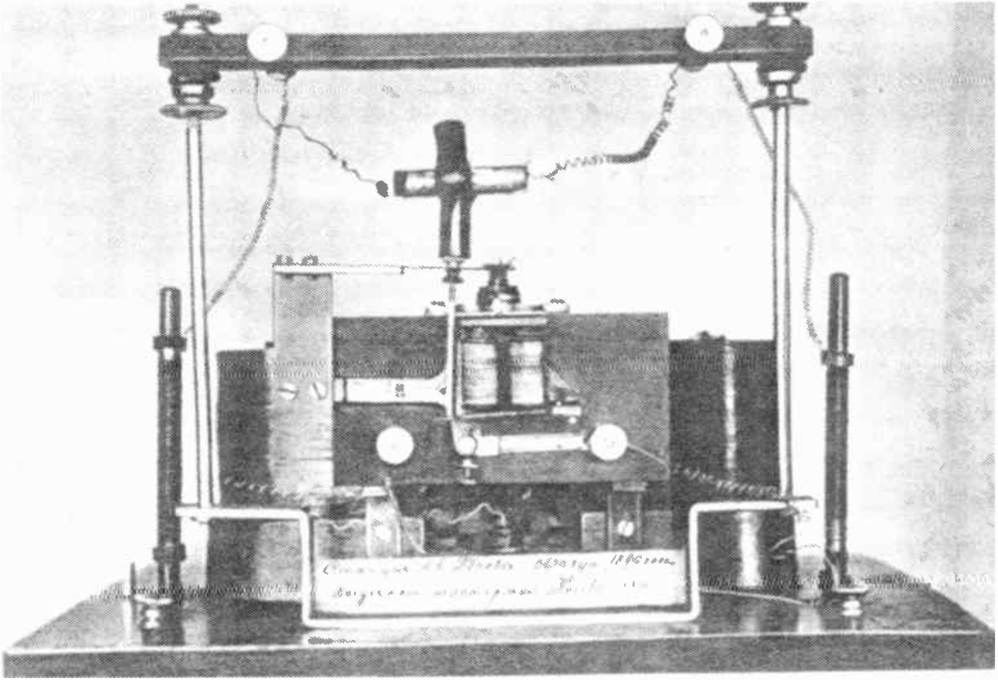
* The *Kotlin* newspaper, December 30, 1897, No. 293, p. 2.

the practising crews of both ships exchanged, one hundred and twenty-six service telegrams were transmitted in the course of less than two weeks, from August 21 to September 3. And during the storm that occurred on September 3, wrote Popov in his report, the wireless telegraph was the only means of communication between the ships.

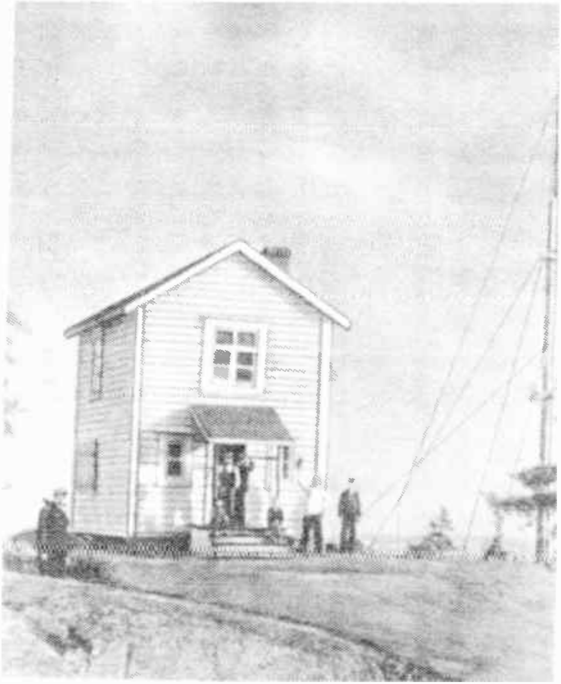
However, the successful experiments at sea did not yet solve the problem of equipping the Navy with radio. Trained radio-men and mass-produced radio equipment were needed before wireless telegraphy could be introduced into the Navy. And Popov was a pioneer in this matter too. He himself trained the first radio telegraph-men, who formed the first group of Russian radio specialists, and who, on Popov's proposal, were to become instructors in the training of new specialists. In a memorandum to the Chief Torpedo Inspector dated January 23, 1899, Popov described in detail this urgent task of the Navy and pointed out that the men detailed to help in the experiments conducted during the past two years had already acquired a certain degree of skill and could be instructors if they were released from their other duties. Popov recommended that new men should be selected immediately and commissioned to the existing wireless installations, thus initiating the planned training of specialists in this new field.

In this same memorandum, Popov suggested a number of measures connected with the manufacture of radio equipment, which was begun under his supervision in Kronstadt in the workshop of Lieutenant Kolbasyev.* It might be noted in passing that radio equipment began to be manufactured according to the ideas and direct instructions of Popov not only in Russia but also in other countries. This may be seen from Popov's above-

* Yevgeny Kolbasyev was a prominent inventor, known in the Navy for his work in the signal field.



Popov's radio station made in the shop of Lieutenant Y. V. Kolbasyev



Radio station on the Island of Kutsalo

Radio station on the Island of Gogland

mentioned memorandum to the Chief Torpedo Inspector in which the inventor of radio gave a comparative review of what had been done during the past two or three years in Russia and abroad in the field of wireless telegraphy.

Popov had every right to finish his memorandum with the claim that radio technique abroad had followed the route he had opened up. He wrote: "Concluding, I may add that the facts published to date concerning experiments in foreign countries indicate that all of them have almost identical apparatus, and if there were cases of telegrams being transmitted over distances greater than those attained by us, it was always achieved through the use of special masts higher than those on our ships and placed as far as possible from metal rigging, which we haven't as yet done. Still, the distances reached in our conditions should be considered as good, and we may assert with assurance that specially devised light masts, especially on non-spar ships, will give distances that for the majority of cases are sufficient." It might be recalled that in Russia, only Popov was engaged in wireless telegraphy, and he had only one trained associate, Rybkin. The situation was different abroad (and not only in Britain), where whole companies with scientists and engineers at their disposal were at work.

Popov kept close watch of events in other countries and made a careful study of everything that appeared in the scientific and technical press. But having become deeply engaged in the practical work of establishing a system of radio communications, he was not satisfied with the information found in the literature concerning the building of radio stations and the mass production of radio equipment that had just begun abroad. He decided to see for himself what was being done in other countries, and applied to the Chairman of the Naval Technical Committee with a request for a month's commission abroad, which was granted the very next day, on April 13, 1899. Popov wanted to see what other countries were doing in the manufacture of radio equipment which the competing firms eagerly exhibited in scientific-technical societies and at exhibitions. Besides, he made every attempt to investigate personally the experiments being conducted by foreign scientists and in particular the researches of the German professor Slaby. Popov also intended to utilize his stay abroad to learn about the system of teaching the subject of electrical engineering in special higher educational institutions recently established for training specialists in this technical branch. It was just at this time that the Torpedo School introduced a course in electrical engineering, to be conducted by Popov.

Popov was satisfied with his trip abroad. The conclusions he arrived at in his memorandum to the Chief Torpedo Inspector were confirmed once more. While in Germany and France, Popov saw with his own eyes that the work he had done was not inferior to what was being done abroad. In a letter to Rybkin dated June 1, 1899, he wrote: "I saw everything there was to see, I spoke with Slaby and saw his apparatus, I visited Blondel at the station in Boulogne; in short, I learned everything there was to learn and I see that we're not far behind the others."

At this time, a new discovery had been made in the field of radio in Russia. Rybkin and Troitsky, during experiments in wireless telegraphy, noticed that it is possible to receive signals by ear. Rybkin related the following: "In 1899, the Chief Engineering Management permitted experiments in radio telegraphy between the forts of the Kronstadt fortress. But since Popov at this time was leaving on his commission abroad, he entrusted the experiments to me and the chief of the fortress telegraph, Troitsky.... It was decided to concentrate the first preparatory experiments at Fort Konstantin, where there was a convenient mast, and at Fort Milyutin, the one closest to it.

"However, the receiving wire that it was possible to raise on the 14-metre mast at Fort Milyutin obviously did not receive enough energy for a sensitive tube, because the relay did not in the least respond to the pulses coming from Fort Konstantin. To determine the cause it was decided to check to see that the receiving circuit was in order. And when doing so, the earphones I had connected up in place of the relay, all of a sudden detected very clearly all the incoming signals.... The sensitivity of the new method of reception was soon confirmed once again. On June 11, signals were received at a distance of 36 km. between Fort Konstantin and the village of Lebyazhye, the receiving wire being raised very high with the aid of a kite.

"I decided to inform Popov at once about all these unexpected results of our experiments, and sent him the following telegram: "New property of coherer found." Despite such brief information, Popov guessed the extreme importance of my discovery and cancelling a prearranged trip to Switzerland, he returned to Kronstadt on June 14. Here he carried out personally all the experiments and worked out the arrangement of an ear-phone receiver. Later he received a patent for it not only in Russia, but also in Great Britain and France."

At that period, experiments in Russia were conducted only in the Naval Department, and at that only on the Baltic Sea. It is quite obvious that work on a much greater scale was needed in order to supply the Navy with radio equipment, and the Black Sea fleet, which did not have any specialists trained in the new field, should also have been included in this work. The initiative here was again Popov's. Popov raised this question as early as January 1899, in the memorandum to the Chief Torpedo Inspector quoted above. As a result, during the campaign of 1899 he left together with Rybkin for the Black Sea, having given up his position as manager of the Nizhny Novgorod fair electric station. It was only now that the authorities higher up realized that it was not economical for an inventor of radio to spend all his time outside lectures on work that could be handled by a more or less experienced electrical technician. But the question of remunerating Popov remained for a long time in the air. And as we have seen, only after both his invention and his unparalleled experience and knowledge had performed extraordinary services for the Navy was an application filed for compensation for the loss he had sustained by giving up his work in Nizhny Novgorod.

Leaving for Sevastopol, Popov realized that the time had come when it was important, no matter what the sacrifice, to direct every effort to introduce wireless telegraphy into the Navy, and that any further delay would result in irreparable loss to the country's defence.

In his memorandum to the Chief Torpedo Inspector, Popov proposed that an immediate decision should be taken to outfit the ships of the Russian Navy with wireless telegraphy, pointing out that abroad the new means of communication was already a part of the sea and land forces.

"Aside from the convenience," wrote Popov, "which the wireless instruments offer in establishing convenient and rapid communication between the ships of the squadron in everyday life, these instruments are invaluable during fogs and stormy weather, when other means of communication cannot be used. This method of communication may be of no small value in time of war at night, when light signalization may be out of place, and especially for communication of destroyers and reconnaissance ships with the squadron at night: the lack of such facilities during the Spanish-American

War resulted in an American squadron firing upon its own ships, at night time of course.

"I shall not attempt to discover and indicate those cases where wireless telegraphy may be of service (all such cases are better known to sailors), but I believe that even having in view the present state of the matter, the new method of communication between ships should be made common practice, and I request of Your Excellency that the question be raised for the official sanction of the Committee being given to equip the ships of our Navy with these new instruments."

Under such circumstances, it was obvious that experiments on the Black Sea and the training there of personnel to man these new-type signal installations would be necessary. The sluggishness of the higher naval authorities (and this will be spoken of again and again) was the reason why no one, aside from Popov and Rybkin, was trained for the practical supervision of introducing wireless telegraphy into the Navy. And in the Black Sea fleet also, they were investigators and instructors.

The campaign of 1899, that achieved a communication distance of 30 km., was the last stage in a period which in official documents was called "experiments in wireless telegraphy according to the method of Popov." The results achieved in this campaign and the experience of the preceding two years served as a basis for radio communications in the Navy which, at the beginning of the following year, developed into news that roused the whole world. This was the Gogland installation that played an exceedingly important part in rescuing the battleship *General-Admiral Apraksin* and in saving a group of fishermen that had drifted out to sea on an ice-floe.

In the autumn of 1899, the battleship of the coastal defence *General-Admiral Apraksin,* having completed its summer cruise programme, received orders to go from

Kronstadt to Libava (now Liepaja). The battleship had hardly left Kronstadt when a snow-storm began in the Gulf of Finland. Despite the squalls, the battleship continued on its way. When passing by the Island of Gogland, the commander of the ship, V. V. Lindenstroem, Captain, 1st Rank, took the light of the southern beacon of the island for that of a passing ship and turned aside to let it pass. As a result of this mistake, the battleship ran ashore on to the rocks at 4 o'clock in the morning of the 13th of November at the south-eastern tip of the island.

The search began for a way to save the expensive ship, which was obviously in peril: the gulf was beginning to freeze over, and if the battleship survived until warmer weather it would be crushed to pieces in spring by the moving ice-floes. Nevertheless, the Admiralty displayed its usual sluggishness. The question of establishing communication with the shore arose only a month after the *Apraksin* had run on to the rocks of Gogland. Since the gulf began to freeze over, there could be no question of using cable. Therefore, the Naval Technical Committee appealed to the Manager of the Ministry of the Navy with the proposal to establish wireless telegraph communications between the island of Gogland and the town of Kotka, situated on the northern shore of the Gulf of Finland.

The first memorandum of the Chairman of the Naval Technical Committee, Vice-Admiral Dikov, to the Manager of the Ministry of the Navy, Tyrtov, was dated December 10. Radio communication was spoken of only in the form of a supposition. Dikov wrote: "If there should be any need to establish communications by wireless telegraph between the island of Gogland and the continent, the facilities at our disposal are entirely sufficient for this purpose."

Meanwhile the Naval Department was in possession of data that left no doubt as to Popov's ability to cope with the task which Dikov spoke of in his memorandum to Tyrtov. In this memorandum, the Chairman of the Naval Technical Committee referred to results that had been achieved in the campaign of the summer before when during the experiments on the ships of the Black Sea fleet, Popov succeeded in communicating signals over a distance of up to 30 km. He pointed out that these experiments had been conducted after Popov's closest associates, Rybkin and Troitsky, discovered the possibility of receiving signals by ear, and that that greatly increased the distance over which communications could be transmitted and received, and simplified considerably the radio-telegraph arrangement.

The material obtained, Dikov pointed out, makes it possible (given an aerial of the proper height—140 to 150 feet) to establish stations in Kotka and on the island of Gogland, and thus make contact with the *Apraksin*. But, nevertheless, for greater security it was suggested that an intermediate station should be established on the island of Ranke, at a distance of about 10 km. from Kotka and 25 km. from the Island of Gogland. Dikov noted that the Naval Department had at its disposal all the necessary means for the building of these structures and that the apparatus might be brought to the Island of Gogland via Revel (Tallinn), and by rail to Kotka and Ranke.

The Naval Department at that time had not only equipment. The men who had participated in Popov's experiments were prepared for the construction and maintenance of the proposed stations. In his memorandum, Dikov emphasized that "the crews of all three stations could be transported with full equipment by Kronstadt." He proposed that Popov and his assistant, Rybkin, should supervise the construction of the station, the actual work to be in the hands of an experienced officer with an assistant from among the officer electricians.

It was decided to build three stations. The necessary apparatus was in full preparedness at the Torpedo School. The participants were divided into two groups: one to go by sea via Revel to Gogland, and the other by rail to Kotka. The first party was headed by Captain 2nd Rank Zalevsky, who headed the expedition, and the second by Lieutenant Remmert. Rybkin was commissioned to Zalevsky's party, and Popov left for Kotka. When on December 16 Zalevsky arrived in St. Petersburg it turned out that the Island of Kirkkomansari, which was located at the same distance from Kotka as from Ranke, was connected with the continent by telegraph, and so the idea of an intermediate station was dropped.

The list of persons to participate in the expedition was approved in St. Petersburg. Among those commissioned to Gogland and Kotka were sailors who had taken part in Popov's experiments on the Baltic Sea and the Black Sea. By the autumn of 1898 the Chief of the Kronstadt fortress telegraph, Captain Troitsky, who from the very beginning had helped Popov in his investigations, built a station in the town of Oranienbaum (now Lomonosov), thus making it possible to continue the experiments. Popov used this station to train the members of the expedition.

Detailed instructions were drawn up in Kronstadt to be used at the future stations.

A week after the list of participants in the expedition had been approved, Remmert was already in Kotka and had begun building the station. A survey of the locality convinced him that the best site for the station was the Island of Kutsalo, situated not far from the town of Kotka and connected with it by a telegraph line.

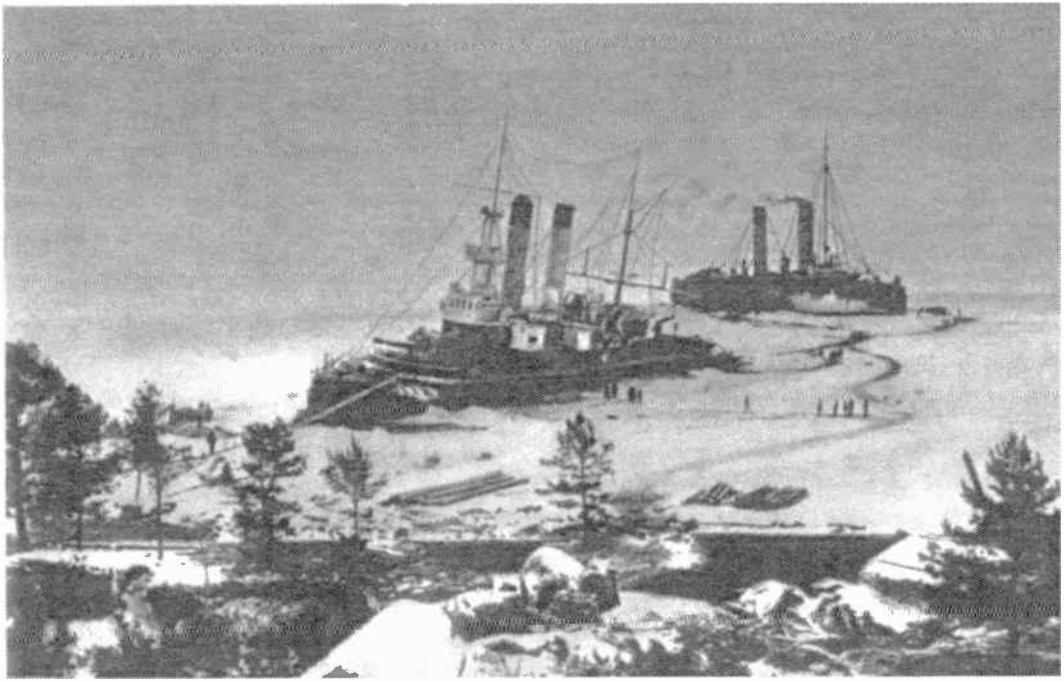
The situation was much worse with the party headed for Gogland. Because of a lot of red tape, it arrived at its destination only in a month's time, on January 14, 1900.

Zalevsky left St. Petersburg for Gogland via Revel on December 19. In Revel he immediately began the construction of a mast and a prefabricated house for the station. The crew arrived on January 7 on the ice-breaker *Yermak,* that was to convey to Gogland the station equipment and other freight for the *Apraksin.* Loading took more time than had been anticipated, and the ice-breaker left the harbour only on January 13, arriving at the *Apraksin* on the 14th.

The unpropitious beginning did not, however, dishearten the head of the expedition. In his report, Zalevsky wrote: "Judging from dispatches, Remmert is doing a very thorough job at Kotka, and, therefore, the only delay so far is in the impossibility of reaching Gogland.... I am not only fully confident of complete success in establishing communications between Gogland and Kotka, but I have certain grounds for believing that it may even be possible to carry on conversations between Gogland and Kronstadt, and for this reason, having in view the given possibility, I shall select a suitable spot for erecting a mast on Gogland."

When Zalevsky wrote these lines (January 5), work on the station on the island of Kutsalo was coming to an end. On January 4, the station house was assembled, and the mast was soon put up. This Remmert reported by telegraph to Popov. On January 7 Popov arrived at Kotka. He and Remmert then left immediately for Kutsalo and began testing the instruments. Popov was satisfied with the work, but pointed out that the trees in the vicinity of the mast might interfere with communications. However, Remmert and his assistant had taken that into consideration. The 160-foot mast was set up on a hill about 450 ft. above sea-level and could be extended up another 25 ft. Thus, the height of the mast could be made some 185 ft. Current opinion in the world at that time was that a mast of 135 ft.

Vice-Admiral S. O. Makarov



The battleship *General-Admiral Apraksin* on the rocks near the island of Gc.. l and the ice-breaker *Yermak* was sufficient for telegraphing up to a distance of 42 kilometres.

On January 14, the *Yermak* arrived at its destination and immediately began to establish communication with Kutsalo. Since they did not succeed in transmitting a connected telegram, the next day three officers from the *Apraksin* were sent over the ice to Kutsalo.

As soon as everything on Kutsalo was ready for communication with Gogland, Remmert began a log, under the heading, "The Log of Telegraphy Using the Wireless Telegraph of the Inventor Popov Between the Stations of Kotka and Gogland." This valuable document is kept in the archives of the Navy. The log begins with the following words: "In Kotka, on the island of Kutsalo, construction work on the telegraph was begun on December 23, 1899. It was completed on January 16, 1900. Telegraph communication was conducted over a distance of 41 versts in the direction NE 1°. Lieutenant Remmert." The next entry in the log was made by Popov on the 18th of January at 9 o'clock a.m. It read: "Gogland, Kotka. Have been working three days. Popov. Three officers from *Apraksin* arrived safely yesterday."

As may be seen from Zalevsky's report, Rybkin by this time had set up a station on the *Yermak*, and, using a kite, had received the telegram sent by Popov. But he had not been able to send a confirmation. Not knowing that Popov was on Kutsalo at that moment, Zalevsky wrote to him to Kronstadt on the progress of work on Gogland (the letters were delivered by the *Yermak*, which acted as messenger between the battleship and the shore). The letter was kept among Popov's papers and was published by Kyandsky. "I am happy to inform you," wrote Zalevsky to Popov on January 18, "that today we received several of your telegrams very clearly.... On Sunday (January 16—*Auth.*) only separate letters were received.... Today the wind is strong and it is snowing. The kites were kept up very high and were sent up from the *Yermak*, which is right next to the *Apraksin*, so that we may assume that our future telegraph cape partly shaded the communication. The cape on which the station is being erected is rather high, and from it to the Kotka station is absolutely open space."

Popov received this letter on his arrival in Kronstadt. But on Kutsalo they knew nothing at all of what was going on on Gogland. The attempt to make use of optical signalization proved a failure. On January 19, Popov entered in his log a telegram communicated to Rybkin: "Were watching for signals yesterday but with no luck." Then it was decided to make the mast longer. In his reminiscences, Remmert later wrote that Popov noticed from the very beginning that the mast was not high enough. The log also carries an entry to this effect. On January 21, Remmert entered in his log the following telegram sent to Gogland: "Stopping temporarily communications to raise mast." He then made the following note: "Mast has been raised." As may be seen from Remmert's report to the Chairman of the Technical Committee, the following signal was delivered to Kutsalo on the evening of January 22: "175-foot mast ready," but no answer was received from Gogland.

Construction work on the station on the island of Gogland was then coming to an end. The conditions under which the work was conducted were described by Rybkin in his memoirs: "The wireless station on the Gulf of Finland was built rather quickly.... The conditions were more difficult on Gogland. Near the *Apraksin* there were no living quarters and the radio station had to be put up on an open cliff about a verst to the north of the battleship. Before beginning the construction of the station on Gogland, a large quantity of building material brought from Revel on the *Yermak* had to be transported to the cliff.

"The cliff we selected was 82 feet above the level of the sea and extended out much farther than the other capes. On its top was a flat open space just large enough to erect a telegraph mast and build a house on.

"The greatest difficulty lay in transporting to the cliff all the material that had been brought. Indeed, it seemed absolutely impossible to haul the long and heavy logs over the narrow forest path; to haul them straight over the ice wasn't easy either, because the ice on the shore of the island had piled up into ice-packs five yards high, and the slope of the cliff facing the sea was all iced over. Nevertheless, there was no other route left but this one.

"The mast was the first to be hauled. It was a log 60 feet long, weighing over 100 poods. Everyone present took a hand in helping out, sailors and port hands from the *Apraksin*, and also the islanders. They dragged it with great difficulty through the deep snow, clearing the way with crowbars and shovels and stopping every other minute only to start again with the 'Dubinushka' song.

"It had already begun to darken when we finally arrived at the cliff. Our destination seemed only another step, but it was here that we met our main difficulty: a tremendous ice-pack on the one side and a steep shore on the other had formed a deep gully which it was impossible to get around. We stopped dumbfounded. What was there to do? But it was useless to think, nothing could be done, the mast had to be pulled out and this everyone understood perfectly.

" 'Hey, Funtikov, start the song!' somebody shouted suddenly, and Funtikov, a former sailor rigger, straddling a piece of ice, delivered himself of such a rhyme that the cliff shook with the general roar of laughter, which was followed by 'and it'll go by itself.' The mast just shot across that ice-pack and throwing up a huge cloud of snow with its rear end disappeared in the hollow. All the men who had been clinging to it on all sides flew along with it and then, on the run, they rushed the mast up on to the cliff. Luckily, the greatest damage was black and blue spots.

"The next day already, delivery of goods along that path went more easily and we could begin the preparatory work to erecting the mast. But just then a snowstorm started up, making the work extremely difficult. The next day, the wind was so strong that even the Gogland islanders, who are used to any weather, had to leave the cliff.

"During the next three days, the weather was perfect (a slight frost and quiet) and the work went full steam ahead. The telegraph cliff looked like a real anthill, with simultaneous work proceeding on the station house and on the hoists for erecting the mast; dynamite was being used to gouge out a hollow in the cliff for the mast, and holes were being drilled in the granite for the heads. Work at the cliff began at sunrise and ended in the rays of a searchlight from the *Yermak*, with only one half-hour rest for food and to warm up at the fire.

"By noon on February 5 (January 23), the 165-foot telegraph mast was complete and secure against any stormy weather. Then came the house, a real place to live in, with two rooms, double windows, a good stove, and it was calked and covered with pitched roofing paper on the outside and cardboard on the inside. The same day, the instruments and storage batteries arrived. Everything was put in its place and the station was ready for action."

The first radiogram was received on the island of Gogland on January 24. It was an order of the Head of the Chief Naval Staff, Vice-Admiral Avelan, on the rendering of aid to Finnish fishermen who had been carried out to sea on an ice-floe. It ran as follows:

"To the commander of the ice-breaker *Yermak*.

"An ice-floe with 50 fishermen on it broke away near Lavensari. Render immediate aid to save these people."

est comparable à γ et β, on devra employer les équations complètes (2) et (4). »

TÉLÉGRAPHIE. — *Application directe d'un récepteur téléphonique à la télégraphie sans fil.* Note de MM. Popoff et Ducretet, présentée par M. A. Cornu.

« En mai 1899, M. Popoff, au cours de ses expériences de télégraphie sans fil à grande distance, observa qu'il était possible d'introduire directement un téléphone dans le circuit d'un radio-conducteur et d'une pile, et de recevoir ainsi les signaux hertziens émis à grande distance.

» En juillet 1899, M. Popoff rendit pratique sa nouvelle méthode radio-téléphonique, dont l'importance est réelle puisqu'*elle supprime le relais et le frappeur ou décohéreur automatique* des récepteurs généralement employés en télégraphie sans fil et qu'elle permet la réception des signaux à de plus grandes distances.

» Les postes officiels établis en Russie, par les soins de M. Popoff, entre l'île de Hohland et la ville de Kotka (47 kilomètres), ont pu ainsi fonctionner par tous les temps et rendre de grands services. Sous l'action des ondes électriques, des variations de résistance se produisent dans le circuit : pile, radio-conducteur, téléphone; elles modifient l'intensité du courant dans le circuit; et, par suite, ces variations intermittentes *sont directement perceptibles au téléphone*, même pour des radiations électriques de très faible puissance agissant sur le radio-conducteur.

» La figure ci-contre est celle de ce poste radio-téléphonique; il est très portatif :

» *Br* est le radio-conducteur *Popoff-Ducretet*; il est démontable, hermétique et disposé pour recevoir, entre ses électrodes, soit des grains de charbon dur, soit des grains métalliques, soit des tiges légères reposant librement sur des supports électrodes en charbon. Une charnière permet de donner l'inclinaison voulue, suivant les cas, et convenable à ce système microphonique spécial; il est sensible aux ondes électriques de très faible puissance.

» La monture de ce radio-conducteur *Br* est munie d'un réservoir à fermeture hermétique recevant une matière desséchante que l'on peut renouveler rapidement. Il est ainsi possible de faire usage de métaux facilement oxydables, l'intérieur du radio-conducteur étant à l'abri de l'humidité et du renouvellement de l'air.

The article by A. Popov and E. Ducretet published in France concerning the direct application of telephone for reception of wireless telegraph signals

The Gold Medal awarded to A. S. Popov at the World Electric Exhibition in Paris (1900)

The accident was reported by telephone to St. Petersburg, and from there a telegram was sent to Kotka, whence the order was radioed to Gogland. The chief of the Gogland station, Zalevsky, wrote that the report was received clearly, and was immediately passed on to the *Yermak*. At four the next morning the *Yermak* set out on the search for the men and returned at 5 o'clock in the afternoon with all of them on board.

News of the fishermen being saved from imminent death through the use of wireless telegraphy, which conveyed to the *Yermak* the message, spread throughout Russia. This was the first case that showed up the marvellous qualities of the new means of communication and it was evident that radio had come of age. The success of Popov's method of communication was of great importance in the work he had begun. Beginning with 1897, the name of Popov was in the headlines not only of the scientific and technical journals but also of the general press. The brilliant victory in the Gulf of Finland increased a hundred times the popularity of the inventor of radio.

The very next day after the saving of the fishermen Popov was swamped with telegrams of congratulation expressing pride and admiration for this achievement of Russian science. The victory of Gogland also belonged to Makarov* who designed the *Yermak* and on whose initiative it was built.

All the more dear to Popov were the lines of Makarov's telegram of congratulation sent to him on January

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* Stepan Makarov (1848-1904), Vice-Admiral, oceanographer, chief commander of the Kronstadt Port and military governor of the town of Kronstadt. Makarov took part in the Russo-Japanese War of 1904-1905 and perished on April 13, 1904 when the flagship (the battle cruiser *Petropavlovsk*) exploded. The famous Russian painter of battle scenes, Vereshchagin, also perished in this explosion.

Makarov was one of very few higher naval officers who realized the importance of the work of Popov and supported it.

26: "On behalf of all the Kronstadt sailors I heartily congratulate you on the brilliant success of your invention. The opening up of communications by wireless telegraphy between Kotka and Gogland over a distance of 43 versts is a victory of the greatest scientific importance." The same day Popov received a telegram from the head of the Torpedo School, Dabich.

New successes followed immediately. The same day that the *Yermak* left in search of the fishermen, a report was received from Gogland that the front rock on to which the *Apraksin* had run ashore had been removed.

January 25 was also the beginning of regular communication between the two stations. The Ministry of the Navy considered that the task entrusted to the expedition had been executed, and the builders of the stations, Popov, Rybkin, Zalevsky and Remmert, were permitted to return, leaving the station to maintenance personnel.

Zalevsky and Rybkin left for Revel on the *Yermak* on January 25 and arrived in St. Petersburg on January 28. Popov left Kotka on January 27.

The brief entries of the chief of the Kutsalo station recorded the outstanding heroism of the Russian sailors. The following is an entry dated February 4: "Wishing at any cost to be able to signal by 9 a.m., we began working almost in the dark, from 6 a.m. It was fate's fortune to test our patience. In the morning the temperature was 26° below zero Centigrade, and reports from Kotka showed 27° below zero, which is 21° on the Reaumur thermometer, and there was a wind that burnt one's face. A sailor Golovin climbed to the cross-trees and stayed there nearly an hour. I asked him whether he was frozen or not. Somehow he had stood it, though he hardly had strength enough left to climb down. It took over two hours to warm him up.... Chunks of ice had formed in place of his whiskers and beard, and it was painful to shout orders because the very hairs on his face pulled out. Quartermaster Menshikov was raised to the cross-trees, and he plunged into the work forgetting the pain in his numb hands; he worked with a fierceness on those cross-trees for more than two hours, and the result was a straight topmast."

Despite such difficult conditions, the stations both on Gogland and Kutsalo worked regularly right up until the *Apraksin* was taken off the rocks and the battleship arrived at Kronstadt by itself, without any help, at the beginning of May 1900. From February to April the station was manned by personnel trained by Popov and Rybkin.

After Zalevsky and Rybkin left Gogland, and Popov Kutsalo, Remmert was left in charge of the work. He continued the investigations in an attempt to increase the distance covered by wireless communications and he reported to Popov on his findings in detail.

Popov reported to the Fourth International Electrical Congress, that took place in Paris in August, on the results of the work conducted. The address entitled, "The Direct Application of a Telephone Receiver in Wireless Telegraphy" was read by Shatelen. It ran as follows: "Transmission was conducted regularly from February to April during the saving of the battleship. At the same time one station was installed on board the battleship. In the course of 84 days 440 official telegrams were exchanged at regular hours. The largest message, which was carried by the newspapers, was 108 words, reporting that the battleship was saved. For two days communications were interrupted because of a storm. But immediately afterwards they were re-established. The snow fell so fast that it was impossible to see anything at more than two metres, but it did not interfere with the regular functioning of the instruments. It may even be said that the state of the weather improved the hearing, since the effect of atmospheric disturbances was less. I believe this case to be the first in which wireless telegraphy operated regularly and successfully; this proved that wireless telegraphy could be put to practical use between these islands, which before had not had any telegraph communication between them. The distance between Kotka and Gogland is 47 km."

A World Electrical Exhibition had opened up in Paris at the same time the Congress was in session. Popov's radio stations and a number of his original instruments were exhibited there. The jury of the Exhibition awarded Popov an honorary diploma and the Grand Gold Medal.

After the wireless stations had been successfully established on Kutsalo and Gogland and were being operated satisfactorily by junior officer personnel, the Chairman of the Naval Technical Committee sent a memorandum to the Manager of the Ministry of the Navy, in which he mapped out a plan for further work. This same memorandum raised the question of placing Popov at the head of this work and of releasing him from his other positions, with the exception of his main work at the Torpedo School. It was pointed out that Popov's duties allowed him but little time to study problems of wireless telegraphy.

Popov was now exempt from all duties except his main work at the Torpedo School. Popov was given 33,000 rubles in compensation for his salary which he lost by leaving his job at the Naval Engineering School and at the Nizhny Novgorod electric station, the contract with which expired in eight years.

Popov could now devote all his time to his main work, the wireless telegraph. The Naval Technical Committee elaborated measures providing for the installation of radio equipment on all ships under construction and the establishment of regular courses for the training of radio-men in the Navy. These courses began to function in 1900. The lessons were conducted by Popov in accordance with a syllabus that he himself had written. Thus, the Navy was not only the cradle of radio, this new means of communication, but also the first department to begin the training of radio specialists.

This same year wireless telegraphy began to be used outside the Navy. The experiments carried out on the Baltic Sea and the Black Sea, and especially the Gogland operation, were clear indication that Russia possessed rich possibilities for utilizing "the spark telegraph."*

The press, at first the special journals and then the general newspapers, kept publishing reports about the successes achieved through the use of Popov's invention. Radio became an indispensable means of communication in the Army and in the Air Force; radio stations for public use began to be built.

And here also the first steps are connected with the name of Popov. The documents and materials at hand

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* The new means of communication invented by Popov was not at once given a generally accepted name. First it was called "telegraph without wires" or "wireless telegraph"; however, there were objections to these names because they might be used to designate a whole series of different ways of transmitting signals. Shedling, for example, wrote: "Strictly speaking, the expression 'wireless telegraph' embraces all methods of transmitting signs between distant points, if they do not come within the list of ordinary means of telegraphy. Thus, the well-known primitive types of semaphoric signalization, heliographic transmission of signs, signalization with flags, lanterns or the acoustic type—all of these are but different types of wireless telegraphy." Slaby was against the name "wireless telegraph" and proposed the term "spark telegraph," which was current for a short time. But even at that time it was justly pointed out: "It is very likely that at some future date electric waves suitable for the transmission of signs, may be produced without the aid of an electric spark, and then the name suggested by Dr. Slaby will correspond just as little as does the name 'wireless telegraph.'" The attempt to sanction the term "Hertzian telegraph" was a failure because Hertz did not find a practical application for the waves he discovered. The term "radio" as applied to electromagnetic oscillations was introduced by Branly.

show that he was a pioneer in the construction of civilian radio stations. In this respect, a considerable part was played by the position which he soon occupied in the Post and Telegraph Department. The first higher educational institution for training electrical engineers in Russia—the Electrotechnical Institute (now named after V. I. Ulyanov [Lenin]) was under the authority of this department. In 1901 this institute elected Popov professor and the inventor thus became closely connected with the department whose task it was to introduce the new means of communication.

Popov's name is also connected with the building of a wireless telegraph designed for international communications. When the transmission range reached hundreds of kilometres and the Post and Telegraph Department was confronted with the task of establishing radio communications with foreign countries, this department appealed to Popov asking him to tackle the problem. The Popov archives, now kept in the Central Museum of Communications named after Popov, has a paper written by the inventor that contains the answer to an inquiry sent to him by the Chief Management of the Post and Telegraph concerning the possibility of establishing wireless communications between Russia and Bulgaria (Odessa and Varna). Popov acknowledged the fact that the sites for the stations (Odessa and Varna) indicated by the Ministry for Foreign Affairs "suit very well future commercial interests in the development of trade between Russia and Bulgaria." However, if one takes a broader view of the problem and keeps in mind the strategical importance of this radio station, it would seem much more expedient to build it not in Odessa but in Sevastopol. The straight air distance between the two Russian cities and Varna is nearly the same, but the technical level at that time was such that it was much easier to establish radio communications across a stretch of water than over land. Therefore, Sevastopol had unquestionable advantages as far as the technical aspect was concerned.

The building of a radio station unparalleled in world practice necessarily required a series of preliminary experiments. Up till then Popov had dealt with transmissions over distances half as great as that projected for the new station. In order to transmit signals over such a distance Popov considered it necessary to "increase the power of the source of electromagnetic waves and to use a complex network of aerials." Experiments along this line are possible if one has a station on the shore, and another one on board a ship gradually moving away in the desired direction. Only after such experiments would it be possible to begin the building of a station on the Bulgarian shore.

The building of such a powerful station could not even be considered without the participation of Popov, and he answered with a ready affirmative to a request to head the construction work. By this time Popov had left the Naval Department after being given a professorship in the Electrotechnical Institute. However, the permission given to Popov to transfer from the Torpedo School to the Electrotechnical Institute contained the proviso that he would in future continue installing wireless apparatus on the ships of the Navy and would remain an "adviser" on all questions connected with the installation of radio equipment, which work was begun on the initiative of the Naval Department.

Although in word the Ministry of the Navy acknowledged the importance of wireless telegraphy in naval affairs, in deed it did not show any initiative at all. In reality, the Navy remained without radio equipment, and the production of such in the country was at the lowest possible level. The Russo-Japanese War, which broke out in 1904, showed how criminal was the complacency of bureaucratic heads in the Army and Navy. Though they had all the necessary conditions, they did not take a single practical step to organize properly the production of radio equipment and to supply the units of the Army and the warships with it. When Japan suddenly attacked Russia and a squadron had to be sent immediately to the Far East, it turned out that radio equipment for the ships was lacking and that it had to be ordered from abroad.

Long before the Russo-Japanese War the more progressive officers of the Navy realized the great importance that radio would have in combat conditions. Such men as Makarov personally supported and helped Popov and attempted to convince the higher authorities that radio, which was invented in Russia, was making great strides in its development abroad, where tremendous sums were being expended in research work. "Whereas in this country," Makarov pointed out, "where the very inventor of this new means of communication lives and works and is at the height of his creative strength, this matter is limited to such investigations as the latter is able to conduct in the general physics laboratory at his disposal in the Electrotechnical Institute. No one in this country is seriously engaged in training radio specialists, especially radio research workers. Already eight years have passed since Popov announced his great discovery to the scientific world, and he has not yet been given a laboratory where he could develop to the utmost his research work. And he hasn't any specialized co-workers who could devote all their time to investigations and in this way advance the work begun by him." Insulted in his feelings as a patriot, Makarov spoke of the absurd state of affairs in the country, for though radio was invented in Russia, the country had to order radio equipment from abroad.

Makarov made every effort to provide Popov with at least elementary conditions for continuing his work in the field of radio. But the voice of the progressive admiral went unheeded. Popov did not receive a laboratory during his lifetime. And as in other cases, Russia, though the homeland of a number of scientific discoveries and inventions, was rarely the first to apply them practically and on a considerable scale. These discoveries and inventions were usually called to life by the urgent demands of the country's economic development, but they encountered the backward economic and political system of tsarist Russia and could drive forward only with the greatest difficulty.

CHAPTER FOUR

TEACHER AND EDUCATOR

In pre-revolutionary Russia with its very few scientific-research institutions, systematic research was conducted almost exclusively in the educational institutions. It is indicative that these institutions had scientific societies connected with them, including such famed societies as the Russian Physical and Chemical Society, the Society of Lovers of Natural Science, Anthropology and Ethnography, the activities of which make up many remarkable pages in the history of science.

It is hard to name a single prominent Russian scientist whose whole life activities were not connected with either a university or some other higher educational institution. And the pedagogical work of such a scientist formed an integral part of all his scientific work. Especially characteristic were the seminars, practical studies and colloquia which played the same part in scientific studies as did the laboratories. Many of the most important discoveries (and during the second half of the 19th century, nearly all of them) both in the theoretical and applied fields were made in educational institutions. Popov's discovery is an example.

The inventor of radio taught his whole life, from his graduation from the St. Petersburg University until his sudden death at the age of 47.

Popov was offered a position without a stipend at the University to prepare himself for a professorship. And since he did not have a sufficient income, the usual path to scientific work was closed to him. He was soon offered a position as assistant in the Torpedo School in Kronstadt, and here he spent nearly 20 years, during which time he performed the work which brought him fame.

Special works have been written about this educational institution. And it is mentioned in the memoir literature devoted to Popov. These works were written by Popov's closest associates. Georgiyevsky, Popov's junior by five years, gave a most impressive description of the school. After finishing the physics and mathematics faculty of the St. Petersburg University, he took an active part in the work of the same scientific societies as Popov, often meeting him at scientific sessions, conferences, congresses and meetings. He retained very close and friendly relations with Popov right up to the inventor's death, and like all prominent Russian specialists in electricity, he contributed much to the success of Popov's invention. Georgiyevsky was Popov's assistant in the Torpedo School from 1889 to 1894, i.e., during the years just before the invention of radio. For this reason, Georgiyevsky entitled his reminiscences: *Popov's Work on the Eve of the Discovery of Wireless Telegraphy.*

According to Lyuboslavsky, a university friend of the inventor's and later professor at the Institute of Forestry, Popov's position in the Torpedo School corresponded most closely to his innermost desires, for he had dreamed of fruitful scientific work. Lyuboslavsky wrote: "He dreamed of practical scientific activity in the laboratory, activity that would not only allow him to work but would also enable him to exchange ideas and share his knowledge with others. Life and the laboratory, such is the exclusive field for such minds and talents as Popov had."

It has already been pointed out that the duties of the young assistant, Popov (he was then twenty-four), were rather varied, and included the following: he was head of the physics laboratory, he had to conduct practical studies in electricity and magnetism, and he had to deliver a course of lectures in higher mathematics. Popov was assistant for six years, up until 1889, when Georgiyevsky was appointed to this position; but already during his second year at the school, Popov was given an independent course to conduct. In Georgiyevsky's reminiscences we find lines that describe how the assistant teacher, at first entirely unknown, soon became a prominent specialist in electricity, whose opinion was highly valued in the Naval Department.

The teaching load at the school was relatively small, and the teaching of general scientific subjects—physics and chemistry—lasted only three months a year. All the remaining time the teachers could use for scientific work. But during the teaching months, the workday began early in the morning and ended late in the evening. Here is how Rybkin describes it: "Popov's workday began at 9 a.m. Lectures lasted up to 12 o'clock, and then, after a half-hour interval, practical studies began with the Torpedo School cadets, lasting till 3 o'clock. And then studies again from 5 to 8 o'clock in the evening. After the evening lessons, a certain amount of time had to be spent in preparation for experiments and the laboratory work of the next morning, and in all this work, Popov took a most active part."

Popov's love for work was one of his most characteristic traits. He found rest and quiet in his favourite work, which took up all his time. Day or night, holiday or workday made no difference to him. His tireless spirit and unquenchable thirst for creative work always struck those who came in close contact with him.

At Popov's disposal was a splendidly equipped laboratory, but in Kronstadt, which was farther from St. Petersburg than the other suburbs, he had to make the different instruments and apparatus himself. Georgievsky, in the article quoted above, writes: "Kronstadt had neither specialists in precise mechanics nor experienced glass-blowers. Popov learned to work on a lathe and do all the mechanical and glass work. He was an experienced turner both with wood and metal, and a very skilful glass-blower."

According to his contemporaries, Popov was one of those scientists with "golden hands," who are not only able to do everything, including even such small jobs as repairing instruments, that take up no small amount of time, but like doing it. In this respect he reminds us of Faraday, who, unlike his teacher, Davy, did everything necessary for his experiments himself, requiring the services only of an old man, a sergeant on pension, who assisted at the laboratory of the Royal Institute.

Petrovsky relates that in 1896, as soon as Roentgen's discovery became known, all the Crookes' tubes in St. Petersburg were bought up in a day or two. And to get such a tube in Kronstadt was out of the question, but without it, it would be impossible to repeat and continue the Roentgen experiments. So Popov, aided by Kolotov, a teacher of chemistry at the Torpedo School, made the necessary apparatus and was one of the first in Russia to begin experiments with X-rays. These experiments were described in the literature of that time and attracted attention.

The reminiscences of Popov's pupils contain a description of valuable traits that characterize him as a teacher. The greatest impression made on them was his rare talent for explaining his subject matter, and everyone was especially impressed by the means used to achieve his aim. One of his pupils, Savelyev, points out that "he had an extraordinary talent for experimenting, he was exceptionally observant, and had 'golden hands': using the simplest means, instruments made with his own hands, he described his ideas with an unsurpassed gift for clearness."

After Popov's departure from Kronstadt, he left behind in the Torpedo School and in the Naval School of Engineering, where he also taught, many instruments, machines, and apparatus made with his own hands.

Though the laboratory of the Torpedo School was in its time well equipped with apparatus, still there was often a lack. The rapid development of electrical techniques required new instruments; at lectures and in the laboratory it was necessary to demonstrate the latest achievements of this department of applied physics. Having learned of some new discovery or invention, Popov often built even complex machines, using the materials he had at hand. In a memorial address dedicated to Popov and delivered at a session of the physics department of the Russian Physical and Chemical Society, Petrovsky said that the Torpedo School and the Naval School of Engineering kept with the greatest care a collection of small electric machines made by Popov at the time when he received the first news of the discovery of the rotating magnetic field. This fact was noted not only because it indicated Popov's love of work, but also as a proof of his ability to distinguish in the embryo that which promised a rich future.

Popov's closest friends and associates, and the Kronstadt public at large, greatly valued and treasured everything made by the hands of the inventor. After his death, at a conference dedicated to his memory, an exhibition was made, showing not only the instruments and apparatus—those living witnesses of the origin and initial stages of wireless telegraphy—but also the equipment of a laboratory made by Popov himself.

The exhibited instruments show how original were Popov's experiments, which have not been sufficiently discussed in the literature. Engelman relates how Popov's associates had decided to put out a book containing descriptions of Popov's experiments: "The admirers and pupils of Popov recall the many experiments carried out by the late inventor during the many years of his scientific and pedagogical activities. An idea arose among his friends to publish a book containing everything relating to Popov, and to include in it a description of his experiments in order to pass on to the future this valuable and original contribution to science."

Due to circumstances that characterize the position of science and the attitude in pre-revolutionary Russia to the memory of outstanding Russian scientists, this idea remained only a good intention. Not a single private publisher was interested in putting out such books that gave only small editions and, therefore, no profit. Any support from the state was, of course, out of the question. And since the scientific circles had at their disposal only limited funds, which were often insufficient even for periodical publications, the book was never published. But in his speech at this memorial session, Petrovsky dwelt on the more important of Popov's experiments. He spoke of how Popov demonstrated the conversion of thermal energy into mechanical energy; of the experiment that shows the property that poor contacts have of changing their resistance under the influence of electromagnetic waves, which led Popov to his great discovery; of Popov's explanation of the convertibility of a dynamo into an electric engine and back again; of a visual demonstration of the time of a current increase in a circuit which has a large self-induction. The speaker showed a screen with five Geissler tubes made by Popov himself, having varying degrees of vacuum, and in conclusion he showed Popov's radiometer for detecting electromagnetic waves.

Many years later, in 1925, when the Russian public for the first time honoured the memory of its remarkable compatriot and celebrated the 30th anniversary of the invention of radio, Petrovsky in a speech at the ceremonial meeting said: "Among the experiments which Popov showed his audience, there are some that are a truly brilliant combination of simplicity, grace and vividness." As an example he referred to the experiment that illustrates the gradual increase in the current in a circuit having a small resistance and a considerable self-induction.

"In order to show that self-induction during an increase in the current plays the part of a brake, Popov built the following circuit. The current from a source of lighting or, better still, from a storage battery, passes through a common circuit breaker and then is divided into two parts: one of the branches has a variable rheostat and an incandescent lamp, the other has the winding of a large electromagnet, the poles of which are closed by a heavy iron armature; an incandescent lamp is also connected in series with the winding. Both branches then join, passing on to the second pole of the arrangement. At the beginning of the experiment, the circuit is closed and the resistance of the rheostat is varied until both lamps burn with the same brilliance; this indicates that the current intensity is the same in both branches, and therefore, that the resistance in them is also the same. If we now break the circuit and then again close it and observe what happens during the first moments, we are at once struck by the fact that the lamp in the branch with the rheostat lights up instantly, whereas the second lamp, connected in the branch with the electromagnet, takes several seconds to reach full brilliance. In its day, this experiment produced a very strong impression, and when describing the phenomenon of self-induction, it is always referred to as Popov's experiment."

Popov's brilliant experiments were designed for his course of electricity, but they also served at his addresses at the sessions of the physics department of the Russian Physical and Chemical Society. They are mentioned only in the minutes published in the printed organ of the society.

These papers preceded the historic report "On the Relation of Metal Powders to Electric Oscillations." Popov's speeches and lectures on the topics of his scientific investigations, his advice and consultation given to officers of the Navy, and the respect he commanded as a teacher of the most important subject taught at the Torpedo School, all this made Popov stand out among the other teachers. Lyuboslavsky relates: "Both his colleagues, the teachers, and his students, the officers, very quickly and imperceptibly feel subordinated to the incomparable skill of grasping any question and the erudition which permeates every answer and piece of advice given by Popov; not a single question is solved without his advice." Indeed, by this time Popov was recognized in the Navy and in scientific circles as a mature scientist, and even in official papers he was called professor (although this title he received only in 1901).

In Popov's pedagogical career, a special place is occupied by those courses of study that were organized for the first time, namely, the courses of electricity and wireless telegraphy. Delivering these lectures, Popov spoke as a pioneer in electrotechnical, and later radiotechnical, training in Russia.

The teaching of applied scientific subjects is a remarkable fact in the history of higher education in Russia. Prominent investigators, whose names are connected with the origin and development of a number of technical branches, themselves trained future specialists, creating in this way new courses of study. In Russia, for example, such a scientist was Academician Yakobi, whose name is inseparably linked up with the first stage of electrotechnical education that began in the 40's of the 19th century. It is true that for Yakobi this was secondary work, his main work being concentrated in the Academy of Sciences. For Popov, however, teaching was his main work and it continued during his whole life.

Both courses he began to conduct while still in Kronstadt. It is important to note that an interest in one of them (the electricity course) was shown at once by the press. Popov began his lecture course in January 1897 and the local *Kotlin* newspaper reported: "Yesterday, January 24, Popov, a teacher at the Torpedo School, delivered his first lecture on electric motors to a large number of students." The newspaper did not only carry each time news items of Popov's lectures, it also published (March 1) a detailed report of them compiled by Petrov and Makarov. Their notes entitled *On Electric Machines* were published that same year in the organ of the Ministry of the Navy.

They also appeared later in a separate edition with an introduction by Popov.

The new lecture course was considered a very important event and was made special note of in the annals of the Torpedo School. By the end of the 19th century electricity was being used not only for torpedos but also for lighting. Electrical engineering was inseparable from naval matters in general. A sound knowledge of electricity was necessary to naval officers, and they were instructed to attend Popov's course.

A thing entirely new in the teaching field was the radio course, which had not existed before Popov. The radio course, or, as it was then called, "Lectures in Wireless Telegraphy," was begun in 1900. In March of that year, after the new means of communication had so successfully operated during the famous episode with the battleship *General-Admiral Apraksin* when it was taken off the rocks near the island of Gogland in the Gulf of Finland, the Chairman of the Naval Technical Committee, Vice-Admiral Dikov, mapped out certain measures connected with installing radio on naval vessels and brought up the question of training radio technicians, considering this to be of prime importance. In his memorandum to the Manager of the Ministry of the Navy, Vice-Admiral Tyrtov, he wrote: "If Your Excellency will permit us to begin immediately the building of telegraph stations on combat and training ships of the fleet it is then desirable to organize at the beginning of April in the Torpedo School a temporary short course designed to acquaint the officers of the Baltic fleet with telegraph instruments, methods of work and with the construction of a ship telegraph station. Beginning with the new school year, wireless telegraphy could be included in the course of the Torpedo School." Dikov received the permission of the Manager, and he gave instructions, in addition to other orders, to compile a syllabus of instruction for these short courses. This was given to Popov to do. He was also instructed to handle the "organization of training the necessary number of officers and men to operate the apparatus and to conduct signalization by wireless telegraphy."

Popov had time to take only this first step in the matter of training naval specialists in the new means of communication. He did not get to delivering regular lectures at the Torpedo School, for in 1901, when the lecture course was to begin, he was given a professorship in the Electrotechnical Institute at the chair of physics.

This institute was a part of the Post and Telegraph Department that was under the Ministry of Internal Affairs, which controlled the police, the gendarmerie, and the chief mainstay of tsarist autocracy, the Third Department of the Personal Office of His Imperial Majesty. Measures were taken to isolate this educational institution from revolutionary ideas. One of the first clauses of the statutes of the Electrotechnical Institute read as follows: "It is under the direct supervision" of the Minister of Internal Affairs in person. The students were selected with extreme care and during their stay in the institute they were subject to restrictions which no other educational institution imposed.*

But no measures, not even the most extreme, could withstand the advancing revolutionary movement as it gripped the students of the Electrotechnical Institute as well as those of other higher educational institutions.

Popov immediately put all his energy into the building of a physics laboratory, which would help in training electrical engineers called for by the curriculum. The man whom Popov replaced, Skobeltsyn, had begun this work with the very limited funds that were allotted to the head of the chair, who was also in charge of the laboratory. During Popov's time the institute was transferred to a new building and the physics laboratory received several large rooms.

Working in an institution that trained electrical engineers, Popov built up his own course having in view this main task, in conformity with which the topics of scientific investigations that he conducted in the laboratory were drawn up. The memorandum entitled *The General Trend in the Course of Physics and the Immediate Tasks of Scientific Research in the Physics Laboratory of the*

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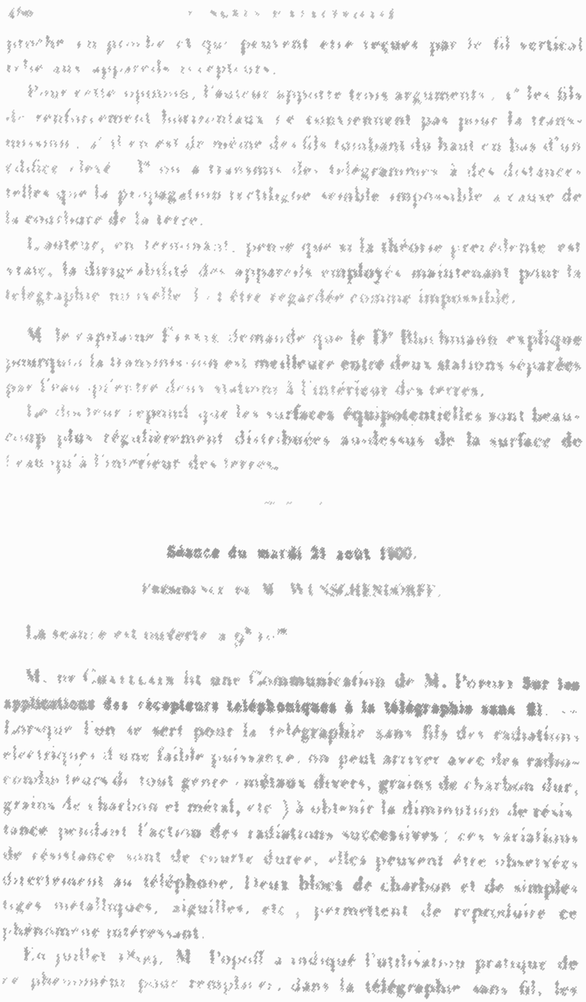
* In the "Rules for the Students of the Electrotechnical Institute" there are clauses of the following type (5-6): "It is absolutely prohibited to express approval or disapproval of any teacher for any reason or in any form," or, "Each student is considered as an individual attendant of the institute, and therefore no action is allowed on the part of the students that may be construed as being collective in nature. In view of the foregoing, it is prohibited to petition in the name of several persons, to send delegates, to put up announcements for the students without the permission of the inspector, to assemble gatherings, to make public speeches either within or outside the institute, to collect money in any way, and the like. Students are also prohibited to organize student libraries, reading-rooms, dining halls, auxiliary loanbanks and other such institutions and to participate in any way in prohibited societies and meetings."



[illegible] [illegible]

[illegible] en [illegible] et qui peuvent être reçues par le fil vertical relié aux appareils récepteurs.

Pour cette opinion, l'auteur apporte trois arguments : 1° les fils de renforcement horizontaux ne conviennent pas pour la transmission ; 2° il en est de même des fils tombant du haut en bas d'un édifice élevé ; 3° on a transmis des télégrammes à des distances telles que la propagation rectiligne semble impossible à cause de la courbure de la terre.

L'auteur, en terminant, pense que si la théorie précédente est vraie, la dirigeabilité des appareils employés maintenant pour la télégraphie nouvelle [illegible] être regardée comme impossible.

M. le capitaine Ferrié demande que le Dr [illegible] explique pourquoi la transmission est meilleure entre deux stations séparées par l'eau qu'entre deux stations à l'intérieur des terres.

Le docteur répond que les surfaces équipotentielles sont beaucoup plus régulièrement distribuées au-dessus de la surface de l'eau qu'à l'intérieur des terres.

Séance du mardi 21 août 1900.

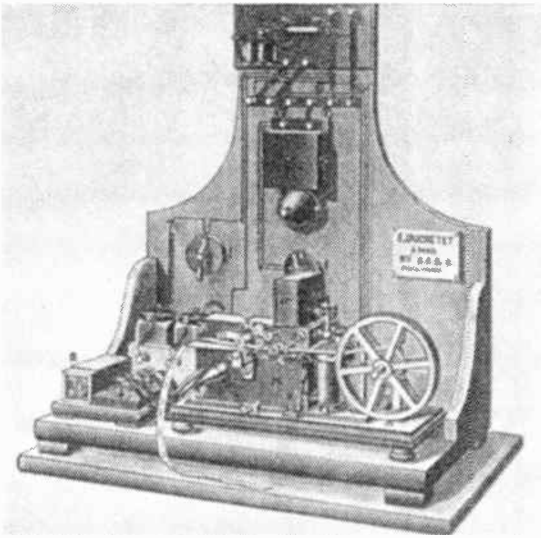
PRÉSIDENCE DE M. [illegible].

La séance est ouverte à 9h [illegible].

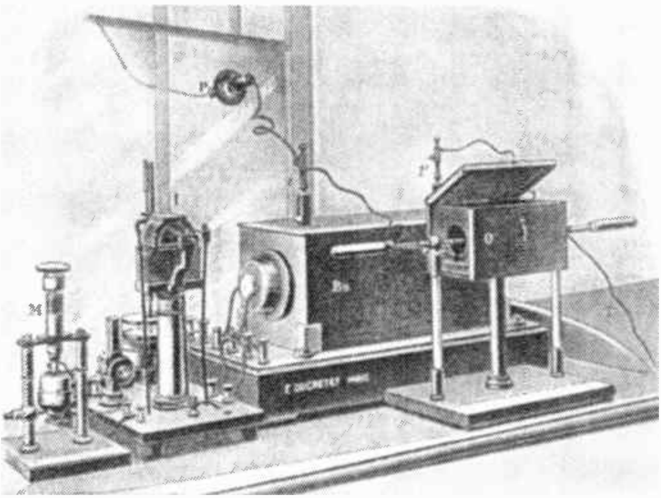
M. de [illegible] lit une Communication de M. Popoff **Sur les applications des récepteurs téléphoniques à la télégraphie sans fil.** — Lorsque l'on se sert pour la télégraphie sans fils des radiations électriques d'une faible puissance, on peut arriver avec des radioconducteurs de tout genre (métaux divers, grains de charbon dur, grains de charbon et métal, etc.) à obtenir la diminution de résistance pendant l'action des radiations successives ; ces variations de résistance sont de courte durée, elles peuvent être observées directement au téléphone. Deux blocs de charbon et de simples tiges métalliques, aiguilles, etc., permettent de reproduire ce phénomène intéressant.

En juillet 18[illegible], M. Popoff a indiqué l'utilisation pratique de ce phénomène pour remplacer, dans la télégraphie sans fil, les

A page from the publication "The International Electric Congress. Paris, Aug. 18-25, 1900." The minutes of Shatelen's speech. He reported to the Congress on Popov's use of telephone receivers in wireless telegraphy



The Popov radio receiving station manufactured by the firm of Ducretet



The Popov ship radio station manufactured by the firm of Ducretet

Electrotechnical Institute that was published, characterizes the line which Popov tried to develop in his subject. He wrote: "The main task of the course of physics is to give the principles of the theory of electricity in such a way that the profound views concerning the nature of electrical phenomena, which were developed through the works of Faraday and Maxwell, should occupy a leading place in the science; and after the famous experiments of Hertz they should not seem inaccessible to ordinary mortals; on the contrary, they should be the guiding principles in the study of electricity."

We have already said that Makarov's attempts to create a special radio laboratory for Popov ended in failure. The only scientific institution that carried on research in the new field of communications was the physics laboratory of the Electrotechnical Institute. It also served as a disseminator of knowledge concerning wireless telegraphy.

At first Popov worked simultaneously in the Electrotechnical Institute and in the Naval Department. He not only supervised the work connected with providing the ships of the Navy with radio equipment, but also participated in the training of specialists in this field. Petrovsky relates the following: "Popov usually came to see us once or twice during the summer to inspect the work and to give instructions. His arrival was considered something in the nature of a holiday and his presence radiated an enthusiasm and excitement."

Popov was not a brilliant speaker. The unforgettable impression he made on his audience was done in other ways. People who knew him well relate that Popov explained the basic concepts of his science with clarity and simplicity, making the essence of the matter stand out and drawing attention to the most important aspects of the problem under consideration. "Like every brilliant mind," Lebedinsky relates, "he left on the subject he taught the imprint of his spirit; and although the experienced reader will not find in his lectures anything essentially new, still he will feel the great strength of the speaker, his power over the subject and his original, clear and comprehensible way of expressing himself."

Georgiyevsky, who knew Popov as a teacher with only a few years of practice, writes: "He always produced a strong impression on his audience by the profound content of his lectures, often by the original way of expressing himself, by the interesting and at times surprising parallels he drew, and by his brilliant experiments which were thought out to the very last detail. Among the officers he was considered an outstanding lecturer; the hall at his lectures and reports was always full."

The success of Popov's lectures was to a great extent due to the carefully prepared and skilfully conducted experiments. The centre of his teaching was experiment. This is the unanimous opinion of all who wrote about Popov as a teacher during different periods, first when he was a budding teacher in the Torpedo School and later as professor at the Electrotechnical Institute. "Popov valued experiments so highly that he tried to do everything before the eyes of the audience," wrote Petrovsky, who confessed that as "a lover of systematic constructions in mathematical form" he at first was sceptical of this method, finding it "too popular for a serious audience." But he was soon convinced that Popov's course was well thought out, and he recognized its full value when it reached alternating current. "All of us know," Petrovsky pointed out, "what doubts plague the student when after integrating the differential equations and not yet sufficiently experienced to grasp the physical essence of the phenomena, he sees crashing to earth the most solid conceptions, those of the continuity of current, of Ohm's law, etc., to a broad interpretation of which he had been accustomed during the study of direct current. It is especially hard to grasp the resonance of currents; one doesn't want to believe that the current intensity in the general part of the circuit that feeds the whole unit could be dozens of times less than the intensity of the current in the branches. And it is precisely here that the experimental method so widely used by Popov in his lectures saves the day. The audience are convinced and see with their own eyes that alternating current possesses peculiarities that distinguish it from direct current, and this in its turn, makes them think further about the subject."*

Popov devoted much time to practical work with the students. At the Electrotechnical Institute he had several assistants who conducted the laboratory work. But the professor was invariably present watching the work of each student.

Just as many other professors who loved their work beyond all bounds, Popov could not be satisfied with the official study schedule. After lectures and laboratory work he used to spend hours talking with the students, for whom these were probably the most pleasant time with their professor. One of his pupils, Savelyev, mentioned above, relates the following: "For us, beginners, many of the terms used in radio were absolutely new; much in electricity was unusual and also new. And to every new question Popov gave a clear, encouraging answer and with such sincerity that one lost all fear of asking again and again and learning his art of experimenting with the radio equipment of that time, which indeed required skill."

As an understanding and responsive professor, Popov talked to the students not only on topics that were directly connected with the course. He was always willing to help his students to solve the scientific problems they were interested in even when the topic was not directly connected with the lecture or the laboratory work. He never grudged time for such talks and attached great importance to this kind of relation of teacher and pupil.

* *Electricity,* No. 4, 1925, p 218.

Popov also kept in contact with the students outside the institute. He would willingly speak even at home to those students who showed a deep interest in the subjects, spending whole evenings with them. One can easily imagine how fruitful were these talks for the future research workers who from the very first year at the institute thus became interested in science. And on the other hand, these talks and the constant contact with young people who infected the tired professor with their youthful energy were useful also to Popov.

Among those pupils of Popov's was Kovalenkov, honoured scientist and corresponding member of the Academy of Sciences. He retained to the end of his days the grateful memory of talks with his teacher at the latter's home, and in bright colours wrote down his reminiscences that were published in connection with the 50th anniversary of the invention of radio. Here is what Kovalenkov wrote: "I knew Popov very well, and during the last years of his life I saw him at his home almost every day. As if today I see his heavy, tired figure in the easy, leather arm-chair. He has just come from the institute and has exchanged his uniform for a comfortable home suit, and with pleasure sinks down into his arm-chair, with his legs outstretched and crossed. Alexander Stepanovich is resting as he awaits evening tea.

"Popov gets very tired at the institute, to which he gives every bit of his energy as head of the chair. He is extremely thorough in preparing for lectures, he works over every single detail and himself takes part in preparing the experiments, and despite his extensive teaching experience he is very nervous before every lecture.

"Alexander Stepanovich has a weak heart and reacts immediately to the mood of the audience. If it seems to him that his lectures are not quite comprehensible to his audience he is upset; he comes home tired and for a long time he can't seem to calm down.

"I, one of his students, was present at his lecture. Now as we are sitting together in his study, he asks me why the students were not attentive. He wants to know what places in the lecture were not clear enough. I try to calm him and explain that the inattention of the students was due to some incident concerning the students; I tell him that it has nothing at all to do with the lecture. I try to convince him that the lecture was, as always, clear and interesting to the students.

"Popov's mood is entirely different when he feels that the audience are interested, when he sees that he has caught their attention. He himself gets excited, his speech flows smoothly and his proofs are more convincing. He comes home still more tired but in good humour. As usual, he sits down into his favourite arm-chair, and our conversation takes on a good-natured, joking tone.

"Tea is ready and we go into the dining-room. The whole family is already seated at the long table. A discussion begins of the day's events, the behaviour of the children, and their progress at school.

"After tea we go back to the study and begin working, we are preparing material for a lithographic edition of Popov's lectures. I take notes at the lectures and go over them at home; he is now correcting my notes, adding and cutting out.

"I am very young and am proud of my close acquaintance with the inventor of radiotelegraphy. We often speak of how the invention was accomplished, and we discuss the general outlook of its development."

The reminiscences of Popov's other pupils also appeared. These sketches record many attractive features in the personality of the scientist.

Other people, who had not studied under Popov but who had begun their scientific career under his guidance working with him in the laboratory or as members of the chair, also published their recollections. All of them considered themselves pupils of the professor. These sketches give a bright picture of those of his traits already mentioned above: he was tactful, responsive, thoughtful of others, and punctual and obliging in his relations with the people he came in contact with, irrespective of their position.

One of Popov's co-workers, Lifshits, who began his well-known investigations in radiotelephony under the supervision of the inventor, relates as follows about their first meeting: "My first meeting with the eminent inventor made an unusually pleasant and encouraging impression on me.

"Popov proved to be very unpretentious and cordial. He was much interested in my earlier works and he wanted to know how I expected to get along in St. Petersburg; he asked me where I was going to live and where I would have meals. He suggested that I rent a room as close as possible to the institute. 'I'll try to fix you up at the institute so that it will be convenient for your work. You get yourself settled here in town and then come over again tomorrow, we'll fix up a place for you to work,' he said as we parted. Later I met Popov every day, and our relations continued with the same cordiality and kindness that struck me so during our first talk. Not once during the whole period I worked with Popov, nor in his attitude towards me or towards the others, did I notice even an inkling of self-assurance, superiority or any attempt to emphasize the magnitude of his own achievements."

Popov and his co-workers conducted their scientific investigations in an entirely new field, working their way over virgin ground. One can easily imagine the difficulties these pioneer radio-men encountered. The only specialist in this branch of applied physics was Popov, and he was always wanted for advice.

The history of science knows many cases when the founder of a new field had to deal with beginning specialists who found it difficult to master the new methods and instruments which seemed so simple to the scientist, who would despair, almost ready to curse the work he had begun. Take the diary of Yakobi. It is full of complaints and indignation concerning the fact that the galvanic workers he was training did not at once become specialists in the electro-torpedo line; and often broke the instruments to the displeasure of their teacher. At times it seemed to him that his pupils would never be useful technicians in combat conditions, but in reality the case was just the opposite. The skill of the Russian torpedo-men in the Crimean War (1853-1856) that soon broke out was unsurpassed, and the enemy acknowledged the superiority of torpedo warfare in Russia.

Popov was entirely different. He always listened attentively to his pupils and corrected their mistakes and shortcomings with great patience trying not to stifle initiative. Shakhovsky recalls with warmth: "He allowed each one of us sufficient freedom in our work; and we didn't feel that unnecessary and petty tutelage that is so often felt with others. He gave general instructions and when the matter demanded it, he immediately introduced alterations. Once in a while he would come into the laboratory during lessons and sometimes he would give advice and then leave. In such cases he was more like a solicitous father than a superior."

The contribution of the founder of this new field of science consists not only in the fact that he was a teacher of young specialists; of not less value was his interest in the training of young scientists, and the stimulation of initiative and the support he lent to any new idea. Such was the scientist and guide, Popov. It wasn't his good fortune to create a large school of followers, for he was head of the chair only four years. But even during this short time, the people who worked with him experienced his beneficial influence. The most prominent of the radio specialists that worked under Popov was Lifshits, who recalls with gratitude his contact with the inventor: "As adviser in scientific work, Popov had the following characteristic traits. He always tried to help a young investigator, but avoided curbing his initiative or imposing his viewpoint. When I encountered difficulties and things weren't turning out the way they should, I asked his advice and support, and I always received it. But otherwise Popov tried not to limit me in any way, allowing me to do as I thought best."

In their recollections, Popov's associates invariably speak of how easy it was to work with him, how courteous and obliging he was with them and with what respect he regarded their opinions as he analyzed in detail their ideas. During all the years that Popov spent at the Electrotechnical Institute, the senior laboratory assistant was Zubarev. After Popov's death, at a meeting held in the Russian Physics and Mathematics Society and dedicated to his memory, Zubarev told about the work of the late scientist in the Electrotechnical Institute and spoke of the relations that existed between the professor and his co-workers. These relations were always most cordial and served as the best possible stimulus in fruitful collective work. "The opinions he expressed," Zubarev recalled, "were always discussed, objections were always treated with the most careful attention, and the desires of his co-workers were always carried out in the most obliging way."

Popov's professorial activities were conducted during the revolutionary events of 1905. Scientific circles in the country were also gripped by the movement against the existing order. Louder and still louder became the voices of dissatisfaction among the scientists. At first these voices of protest were few, but in 1905 they became a united, mass action, which in history is known as the "Letter of 342 Scientists." Professor Popov was among those who signed the letter.

N° 2797 A.D. 1900

Date of Application, 12th Feb., 1900—Accepted, 7th Apr., 1900

COMPLETE SPECIFICATION.

Improvements in Coherers for Telephonic and Telegraphic Signalling.

I, ALEXANDER STEPANOVITCH POPOV, of Cronstadt, Russia, Professor, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

The improved receiver of messages sent into space by means of electromagnetic oscillations, is based upon Branly's discovery of the tubes filled with filings, known as coherers or radioconductors and presenting a great resistance to the passage of electric currents, and adapted to become suddenly conductive when influenced by electric oscillations even when these oscillations have but little strength, which reach said tubes either directly or through conductors secured to the tubes, said conductors serving to collect the electric waves.

The change of resistance is ordinarily accomplished instantaneously and continued after the passage of the electric oscillation; in order to stop the conductibility of the metal filings as quickly as is possible, the tube is ordinarily shaken or jogged and to this end automatic devices have been invented.

My improved receiver comprises the omission of this means for restoring the resistance of the filings, and it will be sufficient to compose my tube with the result to be obtained in view. The result has a real importance and is attained by composing the tube of a conducting chain formed of carbon and metal portions placed alternately and having what is known as "free microphonic contacts." Thus the changes or variations of the resistance are less remarkable and of shorter duration and constancy. At the first influence, the resistance of such radio-conductors decreasing, it maintains still a certain value, and during all the time of the influence of electric oscillation, said resistance will be varying without it being necessary to shake or jog the tube. These variations of the resistance are easily perceived in the telephone.

Under these conditions the arrangement of the improved receiver, according to the accompanying drawings illustrating the invention by way of example, embodies in its main portion:—a circuit comprising the tube filled with filings, one or more elements of a battery, one or more telephone apparatus in which the operator hears special sounds, which are dry, short or long and correspond to each discharge at the transmitting station; thus at the receiving station I obtain a good reception of the signs of the Morse code. The character of the action of the switch for the induction coil is not at all affected and it is thus possible to distinguish from each other, cablegrams transmitted by different stations and received at different moments.

The employment of the telephone in connection with Hertz's sounding board at micrometric intervals has been realised by Mr. Turpin, but this arrangement is convenient only for classic experiments at short distances, and cannot be combined with my system of tube (special radioconductor) filled with steel grains having free contacts, and producing the shortest distances between them which cannot be obtained by any Hertzian sounding board. My improved device enables me to transmit messages without conducting-wires to very great distances.

[*Price 8d.*]

The British patent granted to Popov for perfecting a coherer for telephony and telegraph signalization

A. S. Popov with his family

The Leningrad Electrotechnical Institute

Instruments designed by Popov on exhibit at the Kronstadt School of Communications named after A. S. Popov. The exhibition was arranged after the inventor's death

The Popov Gold Medal awarded annually by the Academy of Sciences of the U.S.S.R. to Soviet and foreign scientists for outstanding scientific work and inventions in the field of radio

This document merits special attention. At the end of 1904, Professor Vernadsky, of the Moscow University, made an appeal to Russian scientists to unite and carry on the struggle together against the fettering system that converts colleges into barracks and professors into police. The Minister of Education, Bogolepov, demanded that the "professor in his work should express and put into practice the views of the government ... he is not only a scientist but a wheel in the bureaucratic machine." Vernadsky, in his article calling upon the Russian scientists to assemble at a special "professors' congress," pointed to the degrading position of the professors and teachers of higher educational institutions. "Both the attitude towards them of the state authorities and administration and their position (provided by statute) within the academic institutions is in complete contradiction to the place which a professor should occupy in the life of his country, and is a drastic violation of the living, state demands of the country. A Russian professor is under special police surveillance. His every step and carelessly spoken word may bring down upon him (and it often has) police and administrative retribution, and as a result his activities have ceased, he has been fettered, and at times, for many years his scientific work has waned. If the professor has not become a part of the bureaucratic machine and if he has not joined the forces that actively support the bureaucracy of the police in strangling the country, his whole life may be spent in the stifling grips of a police-type surveillance; he cannot be sure that by a whim of the administration and for reasons unknown to himself he may not one fine day be discharged and torn away from the work that has become a part of him. And this may occur in the most brutal and demeaning way, without any possibility for him to find an explanation for it and understand what has happened."

Vernadsky's article was warmly received in the scientific circles of the country. An idea arose among the scientists of the capital to draw up a memorandum on the situation and on the needs of both secondary and higher education and to read it at a banquet that was to mark the 150th anniversary of the Moscow University as a holiday of Russian science. The banquet did not take place, but the memorandum was written and named "The Needs of Education." It was signed by 342 scientific workers and published. The very next day the editorial office of the newspaper began receiving statements, both collective and individual, from the members of educational and scientific institutions with the request to have their signatures added to the list under the memorandum.

"According to the very character of its mission," the memorandum reads, "higher educational institutions should train active members of society and honest and public-spirited citizens. But the freedom of investigation and teaching that is necessary to carry out this responsible task is lacking to such an extent that even the purely scientific and pedagogical activities are not guaranteed against administrative pressure. Right up to the present time you may find on the pages of the history of the higher schools cases when professors and teachers (and among them are often outstanding scientists) are forced by the temporary representatives of authority to leave their work for reasons that have nothing whatsoever to do with science. A whole series of orders and measures reduce the teachers of the higher schools to the level of officials, whose duty it is to execute blindly the orders of the authorities. Under such conditions, the scientific and moral level of the board of professors inevitably falls; likewise inevitable is the loss of respect and confidence in the teachers, which is fatal to the present-day life of our higher educational institutions."

The memorandum goes on to say that in order to end such conditions the scientists are joining the growing forces that demand the establishment of "basic political liberties."

These lines were written at the beginning of 1905. The events that followed were in the nature of a tempestuous upsurge of revolution that forced the tsarist government to yield and make certain concessions, and among other things, to permit the higher educational institutions a degree of autonomy, which, by the way, amounted to the directors of the higher schools being elected by the board of professors and teachers from among the most respected and distinguished scientists, whereas before the management of the higher educational institutions was often in the hands of officials, far-removed from science and appointed by the ministry. Thus, the administration of the higher schools was changed nearly everywhere.

The elections of the rector of a university on the director of an institute were an important social and political event. A generally accepted candidate could be a scientist who had recommended himself as a gifted investigator, a teacher loved by the students, and a progressive public figure. The whole faculty of an educational institution had the right to elect their director. At the Electrotechnical Institute, Popov's candidature was agreed upon by the professors and teachers, and at the end of September, 1905, he was elected unanimously.

The director's duties were highly honoured but at the same time they were extremely responsible and entailed great difficulties because of the renewed repressive measures of the reactionary forces in the country. Popov, who had never been in very good health, understood very well that his new position was beyond his strength, but he did not consider it right to reject it. In his address to the professors and teachers of the institute he wrote:

"Dear Friends!

"On September 26 you did me a great honour by electing me unanimously as the first director of the autonomous Electrotechnical Institute. The unanimity with which the election meeting met the wishes expressed earlier at a session of the section of the Academic Union in our institute, deprived me entirely of any possibility to object on personal grounds (no matter what they might be) to my being elected. I considered that in such an important matter as the election of a director, the collective mind should at this period in the life of higher educational institutions, stand above anything personal. As a member of the Council, in which during the four years that I have been in this institute I have not observed the slightest disagreement on matters of any real importance, I could not view the result of the balloting as fortuitously in my favour and considered it my duty as a comrade to accept this extremely difficult post."

No sooner had Popov begun his duties than he came face to face with the worst types of arbitrary rule on the part of the tsarist government. Already two weeks after his election to the directorship, the Council of the Electrotechnical Institute, with Popov acting as chairman, passed the following resolution: "It is the opinion of the professors and teachers of the institute that freedom of assembly constitutes a vital necessity and an inalienable right of the whole population especially at the present difficult time. This freedom of assembly is not ensured by the provisional rules established by His Royal Order to the governing Senate of the 12th of October of this year concerning public meetings. Therefore, the Council considers that it has neither the possibility nor the moral right to interfere with the organization of public meetings on the premises of the institute in any way, including that of closing the institute.

"Any forcible interference by the authorities in the life of the institute cannot improve the situation, it will only worsen it. Improvements in the higher educational institutions may be achieved only by large-scale political reforms capable of satisfying public opinion throughout the country. In the opinion of the signatories, such reforms are: immediate and unconditional guarantees of freedom of assembly, freedom of speech and inviolability of person, the immediate convocation of a Constituent Assembly, the abolition of capital punishment and an amnesty of political criminals."

This resolution was passed on October 15, two days before the promulgation of the Tsar's Manifesto that promised the people democratic liberties. The Manifesto was a political manoeuvre on the part of the autocracy in conditions of the rising bourgeois-democratic revolution of 1905. The promulgation of the Manifesto was an attempt on the part of tsarism to save time in order to muster its forces in an attempt to defeat the revolution. Soon brutal persecution followed, and it hit the higher schools, especially the student revolutionaries. The heads of the institutions were to blame for such "riots" and Popov very often had to explain matters to the authorities. One such explanation cost him his life. Several days after a visit to the Governor of the city of St. Petersburg, the inventor of radio died.

The circumstances that led him to his grave are described by his daughter. "On September 6, 1905, Father became director of the Electrotechnical Institute. This circumstance proved fatal to him. A wave of strikes passed across the country, and the revolutionary movement engulfed the students. The student hostels were constantly being searched for illegal literature and weapons. Father was indignant about these measures and protested against them. He was constantly upset over it all.

"The student movement grew. The government demanded the most urgent repressive measures against the students. Father was summoned to the Governor of St. Petersburg, and they had a serious talk. The Governor demanded that the director 'take measures' and Father naturally refused: he couldn't go against the youth.

"That day Father returned very upset. Even we children noticed that something was wrong. He was pale, his lips trembled and he stammered. At dinner he sat down in the wrong place, something that had never before happened to him. Later he complained of being tired and he said he had a headache. But though upset and ill and all the time worrying and anxious over the 'riots', he still worked.

"I have kept a record of his illness written by my mother who was a physician. On December 28 my father's temperature went up, but even so on the 29th he went to the institute, and on the 30th he took to his bed never to get up again. On December 31, 1905, at 5 o'clock in the evening he died of haemorrhage of the brain."

To the very last days of his life Popov was active in the pedagogical field giving all his strength and energy and knowledge to his favourite work, that of training highly qualified electricians.

For nearly a quarter of a century, Popov, who opened up a new page not only in the history of science and engineering, but also in human culture as a whole, honourably discharged his duties at his responsible post in electrotechnical and radio training.